Rainwater harvesting and community water security in south-west Uganda

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DECLARATION

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text. It has not been previously submitted, in part or whole, to any university or institution for any degree, diploma, or other qualification.

In accordance with the Department of Engineering guidelines, this thesis does not exceed 65,000 words, and it contains fewer than 150 figures.

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ABSTRACT

Less than 40% of Uganda's population has access to safe drinking water. Municipal water systems rarely reach the poorest, most remote communities, and where they do reach populations, quality and quantity are often inadequate due to poor system operation and maintenance. Decentralised water services, such as rainwater harvesting (RWH) can provide essential water where centralised supply is inadequate or does not reach. The Intergovernmental Panel on Climate Change (IPCC) encourages the use of RWH to improve community water access in sub-Saharan Africa (SSA). Nonetheless, uptake of RWH across SSA is below targets that have been set by the United Nations. If these targets are to be met, further research is needed to understand the drivers and barriers of RWH adoption for water-insecure populations in Uganda.

Water security has become a widely accepted term that communicates the broader social, political and environmental benefits of water-related services. Rather than focusing solely on the materiality of water access in itself, water security frameworks have been used to assess the less tangible outcomes of decentralised water access. For this thesis, a new water security framework was designed based on the perspectives of water practitioners and stakeholders involved in the delivery of water services in south-west Uganda. The framework provided structure to identify and assess the sociotechnical outcomes of RWH access.

The framework includes ten sociotechnical water security goals and is based on a new definition of water security developed for this research: 'water services that contribute to community water security provide sufficient water of acceptable quality for good health, which is affordable and available year-round. They sustain livelihoods and can be equitably accessed across all user-groups. These water services should minimise the risk of local conflict and boost community cohesion and climate resilience. The management of these services should be supported by local and national institutions so they can be reliably sustained over the long-term'. Building on previous research, the water security goals go above and beyond solely describing the fundamental physical characteristics of water provision. Instead, they reference socioeconomic, environmental and technical outcomes. The structure of the framework encourages researchers to collect a range of qualitative and quantitative data.

Using a 'two-case' case study strategy, the framework was applied to the assessment of ten RWH installations in a rural (Kabale) and an urban (Mbarara) community in south-West Uganda to identify the drivers, barriers and outcomes of RWH use in the region. Comparisons between the urban and rural community uncovered how localised socioeconomic, infrastructural and governance structures influence the delivery and uptake of RWH in Uganda. For the assessment, a mixed-methods approach was adopted which included water balance modelling, sanitary surveys, site inspections, key informant interviews, focus groups and physiochemical and bacteriological water quality tests.

The significant drivers of RWH use in the rural community were proximity of water in comparison to alternative water sources, the potential for improved livelihoods, protection against climate unpredictability and support from a local NGO. RWH provided good quality water that met World Health Organization (WHO) standards at 80% of sites. There was enough water to support household and micro-enterprise activities. High capital cost was found to be a significant barrier to the adoption of the technology.

The drivers for adoption among the urban community were poor municipal water quality, service interruptions and high costs associated with existing water services. This was compounded by poor sense of value for money and mistrust of the municipal service. In the urban community RWH provided good water quality for 70% of the sites assessed. A lack of awareness and financing mechanisms were highlighted as significant barriers to RWH use. In neither community could RWH provide year-round availability of water and so is most appropriate as a supplementary water source in this region of Uganda.

The identification of the drivers, barriers and outcomes of RWH use in these two communities allows policymakers and water practitioners to better understand which incentives, programmes and mechanisms can support the uptake and sustained use of RWH in Uganda. The water security framework provides structure to assess the sociotechnical outcomes of decentralised water access, emphasising the importance of the human-water relationship to global development.

Aspects of this work have been published and presented as follows:

Publications

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Conference Proceedings

Presentation: 'Rainwater Harvesting as a Climate Adaptation Strategy' - RedR panel event - Climate Change in the Humanitarian Sector - at XL Caitlin, London, June 2018

Presentation and poster: 'Resilient Infrastructure and Climate-Related Disasters' - Tenth International Conference on Climate Change - 'Impacts & Responses', University of California, Berkeley, April 2018

‘Achieving water security by reducing its destructive potential and increasing its productive potential has always been a goal of human society and remains a central challenge for many of the world’s poorest countries today.’

(Grey & Sadoff, 2007)

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

FOREWORD

Prior to beginning this PhD, I worked in sub-Saharan Africa in two of the world's poorest countries, South Sudan and the Central African Republic. At the time, both countries were ravaged by ongoing conflict. As part of my role as a water and sanitation engineer, I took testimonies from victims of the conflict. I noticed a recurring theme in these testimonies, that the most disruptive factor to people's lives and livelihoods, second to the conflict, was the impact of the dual challenges of climate unpredictability and water insecurity. The politics of climate change had not reached these remote communities, and many interviewees were not familiar with the concept. Nonetheless, interviewees clearly described a marked shift in rainfall patterns that was having a devastating effect on crop growth in the region.

On 20 February 2017, the United Nations (UN) declared a famine in South Sudan. While the principal cause of this famine was the conflict, the UN noted that some parts of South Sudan had not had rain for two years, rendering crop growth impossible. More recently, on the other end of the extremes, since July 2020, South Sudan has experienced unprecedented rainfall leading to devastating floods.

These climate extremes are not just impacting South Sudan. Shifts in rainfall patterns have impacted several countries across the sub-Saharan Africa region. Despite being one of the lowest emitting regions in the world, sub-Saharan Africa is predicted to feel the impacts of shifting weather patterns most significantly. In 2019, floods, landslides, droughts and cyclones left at least 33 million people in the region at emergency levels of food and water insecurity (Save the Children, 2019). The effects of climate change will be most noticeable through our relationship with water.

Organisations that deliver aid in fragile states are often forced to adopt a 'band-aid' approach to interventions, meaning that capacity is dedicated to the immediate challenges. Short-term solutions are often the only option available. Adaptation to the dual threats of climate unpredictability and water insecurity requires a deeper understanding of how to best deliver solutions so that they are effective over the long-term. I believe this understanding can come from academic research.

LIST OF ABBREVIATIONS AND ACRONYMS

ASAL	–	Arid and Semi-Arid Land
CAR	–	Central African Republic
CAWST	–	Centre for Affordable Water and Sanitation Technology
CDT	–	Centre for Doctoral Training
CFU	–	Colony Forming Units
DfID	–	Department for International Development
FAO	–	Food and Agriculture Organization
GCM	–	General Circulation Model
GDP	–	Gross Domestic Product
GWP	–	Global Water Partnership
GWSI	–	Global Water Security Index
HDPE	–	High Density Polyethylene
INGO	–	International Non-Governmental Organization
IPCC	–	Intergovernmental Panel on Climate Change
IWMI	–	International Water Management Institute
IWRM	–	Integrated Water Resources Management
KDWSP	–	Kigezi Diocese Water and Sanitation Project
LDC	–	Least Developed Country

MCA	–	Multicriteria Analysis
MEAL	–	Monitoring, Evaluation and Learning
M&E	–	Monitoring and Evaluation
MSF	–	Médecins Sans Frontières
MWE	–	Ministry of Water and Environment
NTU	–	Nephelometric Turbidity Units
NGO	–	Non-Governmental Organisation
NWSC	–	National Water and Sewerage Corporation
ODI	–	Overseas Development Institute
OECD	–	Organisation for Economic Cooperation and Development
POU	–	Point-of-use
ROC	–	Risk of Contamination
RWH	–	Rainwater Harvesting
SDGs	–	Sustainable Development Goals
SSA	–	Sub-Saharan Africa
SSWM	–	Sustainable Sanitation and Water Management Toolbox
TTC	–	Thermotolerant Coliform
UBOS	–	Uganda Bureau of Statistics
UGX	–	Ugandan Shilling
UN	–	United Nations

UNHCR	–	United Nations High Commissioner for Refugees
UNICEF	–	United Nations Children’s Fund
UNISDR	–	United Nations International Strategy for Disaster Reduction
WASH	–	Water, Sanitation and Hygiene
WFP	–	World Food Programme
WHO	–	World Health Organization
WS	–	Water Security
WSSI	–	Water Security Status Indicators

UGX: GBP = 4725: 1

1 INTRODUCTION

Since the publication of ‘A Water Secure World’ by the World Water Council in 2000, water security has become a widely accepted term that frames the multi-dimensional linkages between human well-being and water access. In 2013, the United Nations adopted the following definition of water security:

> *‘water security is the capacity of the population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability’ (UN-Water, 2013).*

With its holistic nature, ‘water security’ allows water practitioners to communicate the broader social, political and environmental benefits of water-related services, rather than focusing solely on the materiality of water access in itself (Jepson *et al.*, 2017). The adoption of this multi-faceted term also reflects the intention of the water community to capture the broad range of factors such as climate change, transboundary dispute and overpopulation, that put water access at risk.

Much research has been carried out into defining water security (Cook & Bakker, 2012; Gerlak *et al.*, 2018; Hall & Borgomeo, 2013; Hoekstra, Buurman & Ginkel, 2018). There is now, however, a need for a comprehensive understanding of how the concepts associated with water security can be put into practice to improve the delivery of water services (Gerlak *et al.*, 2018). In recent years, scholars have developed water security frameworks to assess the relationship between water services and human wellbeing and socioeconomic development. Assessing water services through the lens of water security allows for the less tangible impacts of water access to be identified, helping water practitioners to move away from a narrow 'supply-and-demand' view of water access (Jepson *et al.*, 2017).

Today, nearly half of all people without access to safe drinking water live in sub-Saharan Africa's least developed countries (LDCs) (UNICEF, 2020). In Uganda, only 39% of the population has access to safe drinking water (Water.org, 2018). Much of this demographic does not suffer from physical water scarcity, but instead, from a lack of reliable infrastructure to provide water access (Qadir *et al.*, 2007). Municipal water systems often do not reach the poorest, most remote communities in low-income countries. As a result, eight out of ten people that don't have access to safe drinking water live in rural areas (UNICEF, 2020). Where municipal systems do reach urban populations, quality and quantity are often inadequate due to poor system operation and maintenance. This has resulted in a lack of trust in centralised water services (SSWM, 2018).

Decentralised water services, such as rainwater harvesting (RWH) are often used to 'plug the gap' and can supplement intermittent centralised services or provide essential water where centralised supply does not reach. Rainwater harvesting is an improved water source that uses the roof of a building to collect rainwater for a variety of domestic or productive purposes including cooking, cleaning, washing and drinking (Sturm *et al.*, 2009). Typically, existing household rooftops are used to capture rainfall, which is then directed into gutters that carry the rainwater into either cement or plastic storage tanks.

Staddon *et al.* (2018) estimate that 86% of Uganda's population rely on either 'improved' or 'unimproved' decentralised water sources including RWH, hand-dug shallow wells, groundwater collection schemes and local surface water sources. In comparison with these alternative decentralised water sources, RWH has the advantage of supplying water directly to homeowners, with systems often constructed on household roofs. When RWH systems are well-maintained, the quality of water produced meets standards set by the World Health Organization (WHO). In comparison to groundwater and surface water sources, rainwater is at a lower risk of contamination, making it preferable if climatic conditions suit rainwater collection (Parker *et al.*, 2010).

Goal 6.A of the Sustainable Development Goals refers to '*expanding capacity building support to developing countries in water and sanitation activities including rainwater harvesting'* (United Nations, 2015). In addition, the Intergovernmental Panel on Climate Change (IPCC) encourages rainwater harvesting as a specific technique to improve water access at a community level in sub-Saharan Africa (Bates, Kundzewicz & IPCC, 2008). Despite these policy aims, uptake of RWH across sub-Saharan Africa is below targets that have been set by the United Nations (UN-Water, 2018).

There is evidence to suggest that there are multiple obstacles that prevent the sustained uptake of rainwater harvesting such as high initial costs, system-maintenance challenges, and poorly constructed systems (Lee *et al.*, 2016). However, if uptake of RWH is to meet UN targets, further research is needed to understand what factors drive and inhibit the adoption of RWH.

For this thesis, a new water security framework was designed to assess the sociotechnical outcomes of access to RWH. The framework was developed through consultation with water practitioners who have expertise in the delivery and assessment of decentralised, community-scale water services. Through the application of the framework to two communities in Uganda, the drivers and barriers of rainwater harvesting adoption in one urban and one rural community in south-west Uganda were identified. Comparisons between the two user groups allowed for the identification of how localised socioeconomic, infrastructural and governance structures influence the delivery and uptake of RWH in Uganda.

1.1 Research Aims and Questions

1.1.1 Research Aims

There is still little academic research that links the implementation of decentralised water services to community water security. This doctoral research aims to fill this research gap and add to existing knowledge of how water security concepts can be framed to assess the sociotechnical outcomes of access to rainwater harvesting. Most existing literature that links rainwater harvesting to water security principally looks at whether RWH can supply enough water to meet demand, overlooking the impacts of RWH on human wellbeing and socioeconomic development. Water scholars are now looking to understand the wider water-society relationship, and the less tangible impacts of decentralised water access. The water security framework developed through this research project aims to provide structure to identify and assess these impacts.

Calls for new contributions to water security focus on operationalising water security concepts by applying them to the assessment of water services. In response to this, the framework developed through this thesis has been designed to support water practitioners and researchers in identifying the sociotechnical outcomes of water access. The framework includes ten water security goals, helping practitioners to identify what they should be looking to achieve when delivering water services for better community water security. The framework also provides the basis for post-project assessment of whether water services have been delivered in a way that ensures community water security goals can be met.

The final aim of the research is to contribute to a better understanding of the drivers of, and barriers to, the adoption of RWH for water insecure populations in Uganda. In a region where the majority of the population still does not have access to clean water, identifying what deters and motivates users to adopt RWH can allow policymakers and water practitioners to develop incentives, programmes and mechanisms to support the uptake and sustained use of RWH in Uganda.

1.1.2 Research Questions

This thesis is driven by the following central research question:

Main Research Question: ‘What are the sociotechnical drivers, barriers and outcomes of rainwater harvesting use in communities in Uganda?

A series of sub-questions were developed to represent the various stages of research undertaken to answer the central research question. These sub-questions are as follows:

⇒ Sub-question (1): 'How can the concepts associated with water security be framed to assess the sociotechnical outcomes of rainwater harvesting use in Uganda?'

⇒ Sub-question (2): 'To what extent have specific rainwater harvesting interventions met sociotechnical water security goals in Ugandan communities?'

⇒ Sub-question (3) 'How do the drivers and barriers of RWH use differ between urban and rural communities in Uganda?'

1.2 Thesis Structure

This thesis is separated into nine chapters. **Chapter 1** has described the research aims and questions, as well introducing the concept of water security and briefly stating the research gap. **Chapter 2** details the design of the research study including the underlying philosophy that guides this research, the case study strategy and the role of mixed methods techniques in answering the research questions. Specific research methods are presented. Ethical considerations, limitations and biases of the study are also discussed in this chapter.

Chapter 3 presents the literature review, where publications on water security definitions, metrics, indicators and assessments are discussed. This chapter also details research into rainwater harvesting, with a focus on assessments of RWH through the lens of water security and the use of RWH in Uganda, the case study context.

Chapter 4 describes the development of a water security framework to be used to assess the delivery of water services in low-income communities. The process undertaken to develop the water security framework is presented along with findings from semi-structured interviews with practitioners from the WASH sector and stakeholders involved in the delivery of water services in south-west Uganda. These interviews contribute to the development of the water security framework.

In **Chapter 5**, background on the case study context is presented including socioeconomic data from Uganda and information on the current state of centralised and decentralised water services in Uganda. Details of the two case study communities Kabale (rural) and Mbarara (urban) are described along with local rainfall patterns, demographics and the use of RWH in the two communities.

In **Chapter 6**, findings from the application of the water security framework to the assessment of rainwater harvesting in the rural community case study, Kabale, are presented. **Chapter 7** presents finding from the urban community study and **Chapter 8** discusses comparisons between the two case studies, the role of the water security framework in water project monitoring and the advantages and disadvantages of using water security as a framework to assess sociotechnical outcomes. Conclusions are presented in **Chapter 9** along with recommendations and suggestions for further research and use of the framework.

2 RESEARCH DESIGN

This chapter details the underlying research philosophy that guides the approach and methodology adopted to answer the research questions. The mixed-methods approach used to assess the sociotechnical drivers and barriers of RWH adoption is described, along with details of the data collection process. The ‘two-case’ case study strategy, which included a rural community and an urban community in Uganda is presented along with the rationale behind the selection of Uganda as the case study country. The specific research methods used to answer the research questions are presented. Finally, ethical considerations, limitations and efforts to ensure a high-quality study are discussed.

2.1 Research Design Overview

There are several research questions associated with this thesis, and as a result several different stages of research. A range of methods was adopted to answer the research questions. Table 1 provides an overview of the objectives, guiding research question, data collection and analysis for each stage of this thesis. Initially, a preliminary research question was devised. The literature review was then carried out to identify research gaps. Following on from the literature review, the researcher carried out a scoping study in March 2018 to the case study country in order to ground the research question in real-world settings. The research sub-questions were devised, and the case study communities were selected.

Following on from the scoping study visit, semi-structured interviews were carried out with water practitioners in-person and over video call to inform the design of the water security framework. This was the process used to answer research sub-question (1).

Following the completion of the water security framework, and to answer research sub-questions (2) and (3), field visits took place in the rainy season (September 2018) and the dry season (July 2019). Data was collected in both the rainy and dry seasons, as rainfall patterns differ significantly between the two seasons, and the impact of these patterns on both the functionality of rainwater harvesting units and perceived water security was deemed to be significant. In this way, seasonality was taken into account as a factor that could influence components of water security such as water quality.

	Chapter 3 **Literature Review**	**Chapter 4** **Water Security Framework**	**Chapter 5** **Case Study Context**	**Chapters 6 & 7** **Rural & Urban Case Study**
Objective	To establish how water security is currently defined and assessed	To develop a water security framework for assessment	To identify water security challenges in Uganda and to define the context of RWH	To investigate the extent to which RWH projects in a rural and urban setting meet water security goals
Guiding Question	Sub-RQ (1): Understanding and framing water security	Sub-RQ (1): Framing water security	Sub-RQ (2): RWH interventions and water security in Uganda	Sub-RQs (2 & 3) & Main RQ: Identifying drivers and barriers of RWH use in Uganda
Data Collection	Literature review	Water security stakeholder interviews	Literature review including publicly available data on water services in Uganda	Interviews, focus groups, site assessments, sanitary surveys, water quality tests, water balance models
Data Analysis	Qualitative	Qualitative	Qualitative	Mixed Methods
Outcome	Validation that further research is required to understand water security at a local level	Development of water security framework to structure assessment of water service delivery	Identification of significant challenges with water access for populations in Uganda	Insight into contribution of RWH to community water security. Drivers and barriers of RWH adoption in rural and urban settings in Uganda identified

Table 1 - Overview of research questions, design, data collection methods and outcomes

2.2 Research Theory

Saunders, Lewis & Thornhill (2015, p.124) recommend the use of the ‘research onion’, the diagram featured in Figure 1, to depict the factors underlying the choice of data collection techniques and analysis procedures. In order to make informed choices on how data is collected and analysed, first the outer layers of the 'onion' must be addressed. The outer layer deals with the theoretical paradigm.

Image of research onion removed for copyright reasons. Copyright holder: Saunders, Lewis & Thornhill

Figure 1 - The research 'onion'. Source: Saunders, Lewis & Thornhill (2015, p.124)

Researchers have the option of choosing between a variety of philosophical underpinnings. Broadly, ontological theories tend to fall into two mutually opposing categories – realists and relativists (Morgan, 2010). Realists argue that the natural world exists independently from human action and observation and that this reality can be objectively measured by limiting our own personal biases (Blaikie, 2007, p.10). Associated with positivism, realists use strictly scientific empirical data and facts uninfluenced by human interpretation or bias (Saunders, Lewis & Thornhill, 2015, p.136). Relativism, on the other hand, stems from the ontological concept that knowledge comes from the researcher's point of view and that the external world does not exist independently of our perception (Blaikie, 2007, p.12). Relativists adopt a subjective approach to research and are interested in different opinions and narratives that can account for different social realities (Saunders, Lewis & Thornhill, 2015, p.130).

Pragmatism offers a further philosophical underpinning that endorses theory that informs effective practice. Pragmatists strive to reconcile both objectivism and subjectivism by considering theories, concepts, ideas and research findings not in an abstract form, but in terms of their practical consequences in specific contexts. To pragmatists, knowledge is valued for enabling actions to be carried out successfully (Saunders, Lewis & Thornhill, 2015, p.143). With this in mind, pragmatism was deemed to be the more appropriate research philosophy to support water practitioners in identifying the goals they should prioritise when delivering decentralised water services.

2.2.1 Pragmatism

At the foundation of a pragmatic research approach is the belief that knowledge claims arise out of '*actions, situations and consequences'* (Creswell & Creswell, 2018, p. 14). Pragmatists believe that the problem is most important, and a variety of approaches can be used to understand the given problem. Robson (2011, p.68) explains that for pragmatists, truth is simply defined as 'what works' and the central idea of the research is that the meaning of a concept consists of its practical implications.

The implications of selecting pragmatism as the core research philosophy are that theories, concepts, ideas and research findings are considered in terms of their practical consequences in specific contexts (Saunders, Lewis & Thornhill, 2015, p.143). This approach aligns with one of the main aims of this research – to bridge the gap between the conceptualisation of water security and the implementation of these concepts to assess real-world water services.

2.3 An Abductive Approach

Traditionally, the strategy of inquiry is either inductive or deductive (Creswell & Creswell, 2018, p. 50). Inductive strategies of enquiry begin with no preconceived hypotheses and gather data in order to identify theories. Inductive reasoning starts with observations, and theories are proposed towards the end of the research process (Dudoviskiy, 2017). This approach aims to generate meaning from a data set in order to identify patterns and relationships to build a theory. In contrast, deductive strategies of enquiry begin with a preconceived theory where the goal of the research is to test this initial theory.

A third strategy of enquiry, an abductive approach involves moving back and forth between theory (theoretical evidence) and data (empirical evidence). Data collection is used to explore a phenomenon, identify themes and patterns, locate these themes in a conceptual framework and test these themes through subsequent data collection (Saunders, Lewis & Thornhill, 2015 p.148).

Applying an abductive approach to this research meant obtaining empirical evidence that was sufficiently detailed to complement the theories generated from the literature review. This data was acquired through an initial scoping study to Uganda in the first year of PhD research where the phenomenon of water insecurity in rural and urban communities in Uganda was explored. The goal of the scoping study was to identify communities that suffered from water insecurity, and to understand what types of challenges they faced. In addition, during the scoping study, face-to-face interviews were carried out with water stakeholders in Uganda helping to answer sub-question (1). Data from this scoping study helped to build the theory that rainwater harvesting has a role to play in contributing to community water security in the region.

A water security framework that could provide structure for the assessment of how far RWH interventions had met community water security goals in Ugandan communities was then developed. The framework was designed by interviewing stakeholders involved in the delivery of decentralised water services in Uganda and other low-income countries. To use water security as an assessment tool, water security goals first needed to be defined according to water practitioners with experience in the delivery of water services in Uganda, as they were viewed as the stakeholders that could bridge the gap between the conceptualisation of water security and the use of these concepts to assess the socioeconomic outcomes of water access. Stakeholders involved in decentralised water-provision in Uganda include informal community-based providers, non-governmental organisations (NGOs) and local religious groups among others (Yomo, Mourad & Gnazou, 2019).

The water security framework shaped an understanding of the critical goals associated with a water secure community and provided a structure to assess the contribution of water services to these goals. Finally, the framework was used to assess the extent to which specific RWH interventions have met water security goals in two communities in south-West Uganda. Figure 2 demonstrates the abductive process, moving back and forth between theoretical and empirical evidence.

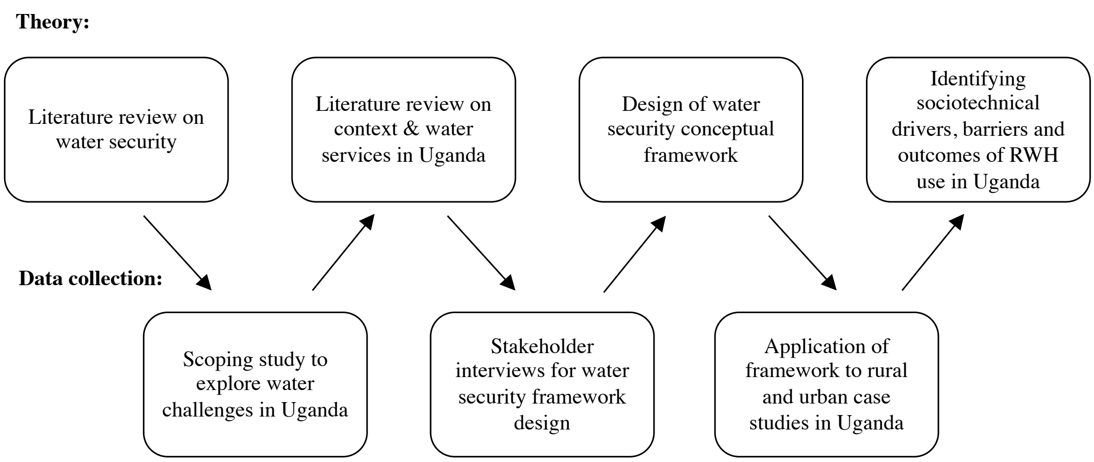


Figure 2 - Application of the abductive approach. Moving 'back and forth' between theoretical and empirical evidence

2.4 Case Study Strategy

Various research strategies including ethnography, grounded theory and a case study approach were considered to investigate the sociotechnical drivers and barriers of rainwater harvesting use in Uganda. Ethnography, where a researcher studies the behaviours of a cultural group in a natural setting over a prolonged period of time, was not a feasible approach to answer the research questions due to funding and time limitations on field visits (Creswell & Creswell, 2018, p.13). Grounded theory, where a theory is developed out of data, was not deemed appropriate for this research project as an initial theory was developed through the literature review, prior to data collection (Bryman, 2008, p. 546). A case study approach was deemed to be the most appropriate strategy. The approach is defined as:

> *'an empirical method that investigates a contemporary phenomenon in depth and within its real-world context when the boundaries between phenomenon and context may not be clearly evident' (Yin, 2018, p.5).*

Yin (2018) suggests that a case study approach is appropriate when the researcher is looking to involve important contextual conditions pertinent to the subject they are studying and favours 'how' and 'why' questions. The term 'case study' is defined not solely as a data collection method, but rather as '*an all-encompassing mode of enquiry with its own logic of design, data collection techniques, and specific approaches to data analysis'* (Yin, 2018, p.14).

The study was designed to take into account how localised factors affect the adoption of RWH (e.g., climate, political structure, financing mechanisms, water supply services). Particularly in the context of low-income countries, factors such as type of water services differ substantially between urban and rural communities, as do programmes to implement these services. A case study approach was therefore deemed appropriate to ensure the role of localised factors could be taken into account when identifying the drivers and barriers of RWH adoption in Uganda.

A 'two-case' case study approach was adopted, viewed by Yin (2018) as preferable to the single case study because the evidence from 'two-case' studies is considered more compelling than a single case study and so is regarded as more robust (Yin, 2018, p.54). Two cases within Uganda (rural community and urban community) were selected because they offer contrasting contexts for community water security to be assessed.

2.4.1 Case Study Country Selection

The scope of this research was to specifically look at sub-Saharan African countries that suffer from water insecurity and have been categorized by the United Nations as one of the world's 'Least Developed Countries' (LDCs). Status of development was a key criterion for choosing the case study location. The researcher's working experience in South Sudan and the Central African Republic (CAR) prior to undertaking the PhD led her to identify significant challenges with reliable water access in the region. Similar water access challenges are found in Uganda, which was chosen as the case study country for this research.

Logistical factors such as in-country safety and ease of access were also influential in the selection of Uganda. To conduct the field research, Afrinspire (UK Charity No. 1095001), a Cambridge-based charity, was liaised with to design a field research protocol. Afrinspire has been working in Uganda for over 20 years on various development projects that focus on water and sanitation, female empowerment, enterprise and agricultural activities (Afrinspire, 2020).

For the scoping study, an itinerary was assembled in unison with Afrinspire that incorporated interviews with local populations, water security specialists and coordinators from charities working in the field of water, climate change adaptation, humanitarian response and international development within Uganda. The aim was to identify what water security challenges rural and urban communities faced in Uganda.

In total during the scoping study, twelve different communities were visited to gain a wide picture of the various water access issues faced by different groups. Through Afrinspire, the researcher was introduced to the Mbarara Plumbers' Association, a local organisation of plumbers that carry out a range of water and sanitation works including RWH installation and masonry. During the subsequent field visits, a representative from the Mbarara Plumbers' Association acted as a facilitator for the urban site assessments. In Kabale, a second charity, the Kigezi Diocese Water and Sanitation Project (KDWSP) was partnered with to facilitate the rural case study site assessments.

Comparative Community Selection

Following on from the scoping study, rainwater harvesting was identified as a potential solution to the dual challenges of climate unpredictability and water insecurity.

Communities where rainwater harvesting was prevalent were selected for detailed assessment for this study. Sample groups that represented two demographics: rural and low income, and peri-urban and medium income were selected. These two user groups had substantially different water access challenges and it was predicted that these two cases would demonstrate different socioeconomic contexts. Additional factors that impacted the selection of the case study communities were the availability and desire of community members to participate.

2.5 Data Collection Process

Figure 3 demonstrates the evolution of field visits. Each field visit lasted three weeks. This timeframe was set due to limitations on funding and in-country travel. Within each community (rural & urban), ten sites with rainwater harvesting installations were selected for detailed assessment. Six sites in each community were household installations, and four were institutional: churches, hospitals, schools and community centres. Focus group discussions, stakeholder interviews, site assessments, sanitary surveys, water quality tests and water balance models were all used to answer sub-questions (2) and (3) and the overarching research question. The same methods were used to assess both the rural and urban communities.

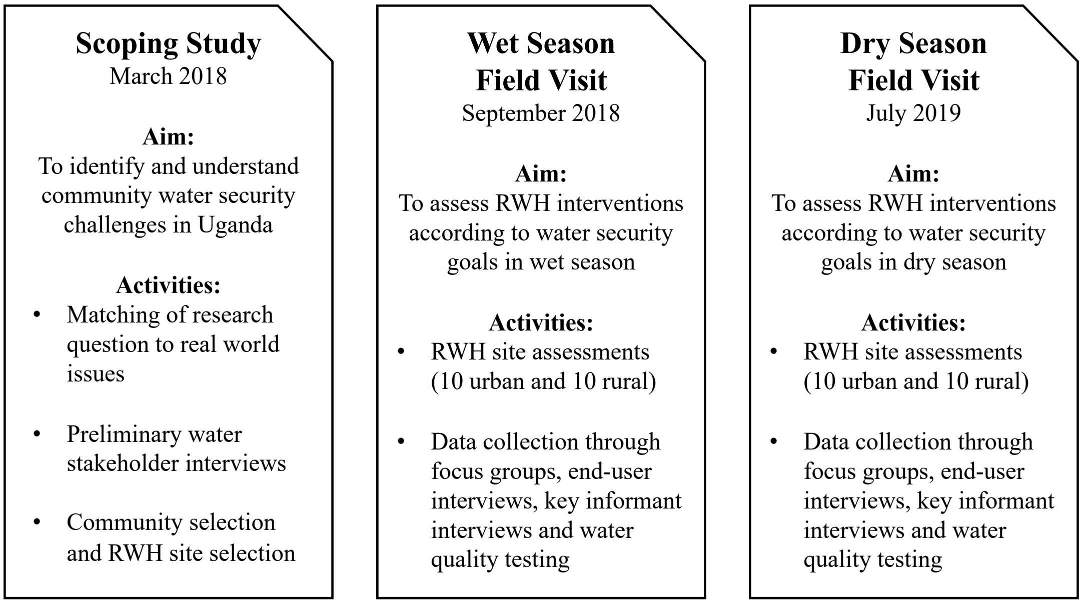


Figure 3 - Progression & role of field visits throughout PhD study

Initially fifteen RWH sites were visited in Kabale (rural case study) and fourteen RWH sites were visited in Mbarara municipality (urban case study). Of these, ten sites in each community were selected for assessment. Criteria for site selection in Kabale were as follows:

- Sites where RWH had been in use for at least two years.
- Sites where owners/site managers were willing to participate in the study including allowing site assessments, participating in interviews and allowing water quality tests to be carried out by the researcher.

Criteria for site selection in Mbarara were as follows:

- Sites where RWH had been in use for at least two years.
- RWH was an additional water source in addition to piped, municipal water. This was in order to understand why users would want to adopt RWH when they already had piped water access.

- Sites where owners/site managers were willing to participate in the study including allowing site assessments, participating in interviews and allowing water quality tests to be carried out by the researcher.

2.6 Mixed Methods Research

Pragmatism is strongly aligned with mixed methods as it endorses pluralism; observation, experience and experiments are all useful ways to gain an understanding of people and the world (Robson, 2011). A mixed methods approach, where researchers emphasize the research questions and use all approaches available to understand the problem, is deemed to be appropriate for research conducted with a pragmatic worldview (Creswell & Creswell, 2018, p. 10). The assumption behind adopting a mixed methods approach for this research project was that a more comprehensive understanding of water security (with its multi-faceted nature) could be acquired by collecting diverse types of data.

Mixed methods research is a growing area of methodological choice that involves both qualitative and quantitative research techniques (Johnson & Onwuegbuzie, 2004). The approach not only uses both qualitative and quantitative methods but also has an explicit focus on the links between the two methods (Denscombe, 2014).

Morgan (2014, p.66) notes that researchers from numerous fields have attempted to create various systems to describe motivations for using mixed methods research. However, instead of explaining the purpose for combining methods, researchers have relied on theories about how they should go about combining different methods. In response, Morgan clarifies that there are three basic motivations for combining qualitative and quantitative research methods – **convergence, addition and sequencing**.

Mixed methods researchers often rely on **convergent findings**, which use qualitative and quantitative methods to address the same phenomenon. This provides greater certainty by showing that methods with different strengths lead to similar conclusions. Convergent findings can also provide interesting insights where contradictory results emerge. **Additional coverage** assigns the different strengths of various methods to the different goals of the overall project. It is pursued when each method can provide a distinct kind of data for the project. Finally, **sequential contributions** link methods so that one enhances the effectiveness of another (Morgan, 2014, p.68).

In the context of this study, the main goal of using mixed methods was 'additional coverage'. Qualitative and quantitative methods were used to obtain depth of understanding of the challenges and opportunities associated with the adoption of rainwater harvesting and how these challenges may be overcome to help meet a community's water security targets.

To initially develop a framework for assessing water security, a qualitative method (interviews) was adopted as a rich, detailed description of the phenomenon (water security) was sought. To *assess* the water security of the two communities involved in the case study, both qualitative and quantitative methods were adopted, as each type of technique contributed to providing a detailed understanding of the extent to which RWH met the various goals of water security (as defined by the framework).

2.7 Methods of Data Collection During Field Visits

The rationale behind collecting diverse types of data was that, given there are many concepts associated with water security, multiple data sources are required to provide a comprehensive understanding of how it can be operationalised. The methods of data collection included qualitative methods (interviews & focus groups, site assessments and field notes), quantitative methods (water quality tests, sanitary surveys) and modelling methods (water balance models).

2.7.1 Site Assessments and Field Notes

Site assessments were carried out at each of the twenty rainwater harvesting sites during the September 2018 (rainy season) field visit and included a checklist of seven questions on the physical attributes of each installation site such as roof material and size, number of roofs in the catchment, type of guttering, tank material and volume and whether the assessment site was a community institution or a private household. Details of the site assessment questions can be found in Appendix II.

Field notes and memos were collected throughout the research process. Field notes provided useful data where formal interviews and recordings had not been prepared. For example, several impromptu conversations took place as a result of the researcher's presence in the communities. These informal conversations were not tabulated as formal interviews. Instead, informal conversations contributed to the researcher's overall understanding of water access in the communities and provided important information on topics from governance, cost structure of rainwater harvesting projects and gender roles in the collection and management of water.

2.7.2 Sanitary Surveys

Sanitary surveys provide a set of questions that can be used to assess the quality of construction and maintenance of water supply. Initially proposed by the World Health Organization (WHO) in 1997, they can provide a simple, risk-based assessment of water sources and are structured to provide clear guidance for remedial action to protect and improve water supply systems (Luby *et al.*, 2008). For this study, the WHO sanitary survey specifically designed for the assessment of rainwater harvesting systems was used.

Sanitary surveys for rainwater harvesting consist of 10 questions (shown below) with 'yes' or 'no' answers. 'Yes' answers indicate that there is a risk of contamination. Each 'yes' is assigned 1 point. Each 'no' answer scores zero points. The maximum risk of contamination (ROC) score for RWH is 10. A higher score corresponds to more hazards present during the survey and thus a greater risk that drinking water is contaminated by faecal pollution (Mushi *et al.*, 2012). Sanitary surveys were used in this study to assess how effectively the rainwater harvesting systems were managed by institutional managers and homeowners.

Sanitary Survey Questions for Rainwater Harvesting Sites according to the WHO (2008):

1. Is there visible contamination on the roof catchment area?
2. Are the guttering channels dirty?
3. Is a method of diverting the first-flush present?
4. Is a filter or any form of water treatment used prior to storage?
5. Is there any source of pollution around the tank or water collection area?
6. Is there an opening to the tank that is not covered?
7. Is there any defect in the walls or top of the tank which could let in water?
8. Is the tap leaking or otherwise defective?
9. Is the cement floor under the tap defective or dirty?
10. Is the water collection area inadequately drained?

2.7.3 Key Informant and End-user Interviews

'Key informant' and 'end-user' interviews took place on the two principal field visits to Uganda in September 2018 and July 2019. 'Key informants' were deemed to be individuals who were knowledgeable about RWH practices within the communities in question. They included community members, NGO and intermediary organisations, the church, plumbers, masons, water committee members, and employees from the National Water and Sewerage Corporation (NWSC). 'End-users' were the homeowners or management staff at institutions that consumed the water from the RWH systems. End-user interviews included questions where interviewees were asked to 'rate' attributes associated with their water access e.g., the taste of water produced by their RWH systems. For these 'rating' questions, a Likert 1-5 scale was used. Further questions were asked on user demographics, RWH maintenance and management practices, water habits and access to alternative water sources. An interview guide for these interviews can be found in Appendix II. The full range of questions was asked to end-users in the first (wet season) field visit. During the second (dry season) field visit, shorter interviews were carried out with end-users, where the focus was on RWH maintenance practices and changes to water access.

All interviews were conducted using a semi-structured approach and were recorded on a digital recorder. Notes were taken during interviews and the interviews were then transcribed. Categories were developed to organise findings through an iterative process of examining the interview transcripts and memos taken by the researcher during the interviews.

Rural Case Study Interviewees (Kabale)

Table 2 provides detail on the range of key informants interviewed along with interviewee codes that are used where quotations are presented to demonstrate findings. Interviews were all carried out in person and lasted from 15-55 minutes.

Role	Number of interviewees	Interviewee Code
Church leader	1	KI01
Community member	3	KI02a, KI02b, KI02c
KDWSP engineer	1	KI03
KDWSP monitoring specialist	1	KI04
KDWSP gender specialist	1	KI05
Women's group lead	1	KI06
Women's group member	3	KI07a, KI07b, KI07c,
NWSC site manager	1	KI08
Mason	2	KI09a, KI09b
Plumber/technician	4	KI10a, KI10b, KI10c, KI10d,
End-users including:		
Community centre site manager	1	EU01
High School Caretaker	1	EU02
Church 1 - Priest	1	EU03
Church 2 – Church leader	1	EU04
Household Site A	1	EU05
Household Site B	1	EU06
Household Site C	1	EU07
Household Site D	1	EU08
Household Site E	1	EU09
Household Site F	1	EU10
Total	**28**	

Table 2 - Kabale, Uganda, rural case study interviewee roles

Urban Case Study Interviewees (Mbarara)

In Mbarara, information from the key informant interviews helped to develop an understanding of typical RWH practices within the city. Key informants were selected based on their relevance to RWH activity and on willingness to participate in the study. Information from the key informant interviews was used to better understand 'typical' RWH users. Table 3 provides detail on the role of key informants.

Role	Number of interviewees	Interviewee Code
Climate change specialist	1	KI01
Community member	3	KI02a, KI02b, KI02c,
Plumber/technician	5	KI03a, KI03b, KI03c, KI03d, KI03e, KI03f,
NWSC site manager	1	KI04
Mason	2	KI05
Afrinspire CEO	1	KI06
Afrinspire Bursar	1	KI07
RWH specialist	2	KI08
End-users including:		
Convent sister	1	EU11
Primary School Groundskeeper	1	EU12
Development Studies Centre Director	1	EU13
Hospital Groundskeeper	1	EU14
Household Site G	1	EU15
Household Site H	1	EU16
Household Site I	1	EU17
Household Site J	1	EU18
Household Site K	1	EU19
Household Site L	1	EU20
Total	**26**	

Table 3 - Mbarara, urban case study interviewee roles

2.7.4 Focus Groups

In addition to key informant and end-user interviews, four focus group discussions were held in Kabale and four were held in Mbarara. The findings from the focus group discussions held in Kabale (two in September 2019 visit, two in July 2019 visit) and in Mbarara (two in September 2019 visit, two in July 2019 visit) were used to triangulate findings from the key informant interviews and to give voice to those community members who were not selected for individual interview.

They also helped to establish a broad understanding of community demographics, socioeconomic status and the challenges faced by the communities that put pressure on water access. Focus group attendees were sought based on their previous use of RWH and their willingness to participate. The key-informant and end-user interviews had been carried out in English, whereas the focus group discussions were conducted with a translator, which allowed for a wider pool of participants to participate in the study.

The rural community focus groups were coordinated by the Kigezi Diocese Water and Sanitation Project (KDWSP) and took place in the local community church. Participants were selected by the KDWSP. This may have meant that participants felt the need to provide positive feedback on the role of KDWSP in the community, given that a representative was present for the focus group sessions.

The urban community focus groups were coordinated by Afrinspire. Adverts for the focus group discussion were placed on lampposts and public notice boards within each community and focus group members were sought from community 'hubs' such as the Mbarara University of Science and Technology, the local church, through the Mbarara Plumber's Association and through community women's groups in the local area.

Table 4 provides further detail on the focus groups.

Field Visit	Date Range	Focus Group Topic	Number of Focus Groups	Average number of participants per group
Rainy season	September 2018	Rainwater harvesting & water usage	4 (2 urban, 2 rural)	16
Dry season	July 2019	Rainwater harvesting & water usage	4 (2 urban, 2 rural)	21

Table 4 - Date, location, topic and number of attendees for focus groups carried out in case study communities

An activity-oriented approach was adopted for the focus group discussions as recommended by Colucci (2007). This approach included rating, ranking, choosing among alternatives, picture sorting, and storytelling. This approach was deemed appropriate as several of the focus group participants could not read or write, and so the use of images, props and activities helped participants to communicate and assisted in overcoming the language barrier between the researcher and the participants. Sessions lasted between 45 and 90 minutes. A focus group guide can be found in Appendix III.

2.7.5 Water Balance Model

Water balance models can provide approximations for the climatic conditions under which RWH systems will or will not satisfactorily meet demand. This type of model gives an indication of the availability and quantity of water provided by RWH. Daily rainfall data for the year from 1st July 2018 – 1st July 2019 were taken from Tutiempo, an online database that provides historic daily rainfall data from local weather stations. Mbarara (urban) and Kabale (rural) weather stations were selected (Tutiempo, 2020). The water balance simulation was designed using Microsoft Excel 2011 (Redmond, Washington, USA). Profiles of the volume of water in the tank over the 1-year period were modelled to assess how often supply would fail to meet demand, whether the size of the tank was suitable for the catchment area and whether RWH can provide year-round availability of water for the two case study communities.

The roof area, number of roofs in catchment, and tank size were measured for each of the twenty sites during the site inspections. Daily household water demand (D_t) was calculated based on the WHO recommendation of 20 litres/day/person x number of people that used the RWH system. An assumption that all demand would need to be met from water produced from RWH was built into the model. This was because it was not possible to obtain an accurate estimate of the volume of water provided by alternative water sources.

The water balance model simulated the rainwater harvesting system at each site considering:

⇒ Daily rainfall (R),

⇒ Roof area (A),

⇒ Tank size (V_{max}),

⇒ Daily household water demand (D_t),

⇒ Water loss due to evapotranspiration (Q)

⇒ Spillage due to tank overflow (SP).

The equations that govern the water balance model are expressed below:

To identify I_t, which is the total volume of water harvested on a given day (t) measured in cubic metres (m^3) the following equation was used:

$$I_t = R * A * Q$$

Where 'R' is the daily rainfall expressed in meters (m), 'A' is the rainwater harvesting catchment area expressed in metres squared (m^2). For this study catchment/roof areas ranged from as small as $24m^2$ to a maximum of $900m^2$. The larger roofs within this scale belonged to community institutions such as churches or learning centres. 'Q' is the runoff coefficient that caters for losses from the catchment area. Typically, runoff coefficients of roof surfaces range from 0.8 to 0.95 (Kisakye & Van der Bruggen, 2018). A conservative runoff coefficient of 0.8 was used for the simulation.

To estimate the daily household water consumption/demand, the following approach was used:

$$O_t = D_t \ if \ I_t + V_{t-1} \geq D_t$$

$$O_t = I_t \ + V_{t-1} \ \ if \ I_t + V_{t-1} < D_t$$

Where O_t is the total volume of water released from the tank on a given day (t) expressed in cubic metres (m^3), D_t is the household water consumption on a given day (m^3) and V_{t-1} is the total volume of water in the tank at the end of the previous day (t-1) with units m^3.

As this was a simulation, the findings from the water balance model were used to provide estimates of V_t, the total volume of water in the tank at the end of the day. This was then used to approximate how many days between July 2018 – July 2019 the tank at each site was empty. In cases where applicable, the number of days the tank overflowed was also noted.

2.7.6 Water Quality Tests

Both laboratory testing and remote testing were explored as options for the water quality tests. Remote water quality testing was chosen as laboratory testing requires the samples to be provided within 24 hours of collection. Because of the remote location of the test sites, and field visit timing constraints, laboratory testing was not deemed to be possible.

Water quality tests were carried out at the twenty test sites during both the dry season and the rainy season using the Oxfam-DelAgua testing kit (see Figure 4). Two sets of samples were tested from each site at each test period in order to increase the reliability of results. Samples were collected in 300ml plastic sample bottles and were tested for pH, turbidity, colour and thermotolerant coliforms (TTC). All samples were collected and tested within 4 hours of collection to ensure accuracy of results. For each sample a 10ml and a 100ml sample were tested as recommended by the DelAgua manufacturers. In total, 104 samples were tested including samples from the municipal water in Mbarara.

Figure 4 - The complete DelAgua remote water quality single incubator test kit

Turbidity

Turbidity was measured in-situ using a turbidity tube. In rainwater harvesting units, turbidity can be caused by particulates from the rooftop. The higher the turbidity, the higher the risk that upon consumption, consumers will develop gastrointestinal diseases (Roos *et al.*, 2017). Turbidity is an important metric because it affects the acceptability of water to consumers and provides an indication of the efficacy of the RWH system in filtering rainwater.

pH

pH is a measure of the acidity of an aqueous solution. The pH of most drinking water lies within the range of 6.5-8.5 (WHO, 2007). The natural pH of rainwater is slightly acidic, as the rain is saturated with oxygen and carbon dioxide. CO_2 forms carbonic acids in rainwater and so the natural pH of rainwater can be as low as 5.6 (Despins, Farahbakhsh & Leidl, 2009). Pollutants, however, normally raise the acidity of rainwater and when rainwater is stored in ferrocement tanks, the pH is significantly raised when the rainwater reacts with cement and absorbs calcium (Martinson, 2007). While pH alone is not a direct indicator of adverse health effects, it can affect the degree to which water corrodes metals in water transmission networks and can impact the efficiency of chemical disinfection such as chlorination (Despins, Farahbakhsh & Leidl, 2009). Consequently, it is an important water quality parameter which can indicate that water is inadequate for human consumption.

Microbiological Water Quality

The membrane filtration method was used to determine the number of thermotolerant coliforms (TTCs) in the water samples. Further details of the procedure to measure microbiological water quality with the DelAgua kit are presented in Appendix IV. Table 5 demonstrates a typical classification scheme based on increasing orders of magnitude of thermotolerant contamination.

TTC Count per 100ml	Category and colour code	Remarks
0	A (blue)	In conformity with WHO guidelines
1-10	B (green)	Low risk
10-100	C (yellow)	Intermediate risk
100-1000	D (orange)	High risk
>1000	E (red)	Very high risk

Table 5 - World Health Organisation thermotolerant coliform thresholds (WHO, 2007).

2.8 Quality of Study

The nature of the study – to investigate and apply the concepts associated with water security to real-world water provisioning projects – is complex. Water security, by its very definition, is a multi-faceted term, and as a result, a variety of methods was sought to answer the research questions. The mixed-methods approach allowed for triangulation between the various data sources, helping to verify, or indeed refute findings. Nonetheless, with a mixed-methods approach, sacrifices were made, most notably, the depth with which the researcher could pursue one line of enquiry. Bryman (2008, p. 41) explains that the two most prominent criteria for the evaluation of social research include **reliability and validity** (including construct validity, internal validity and external validity).

2.8.1 Reliability

Reliability is concerned with issues of consistency of measures (Bryman, 2008, p. 156). Often described as whether the results of the study are repeatable, researchers need to document the procedures of their case studies and document as many steps of the procedures as possible (Creswell & Creswell, 2018, p. 201). The case study protocol and data have been made as transparent as possible for this research project, with clear steps in data collection laid out in this chapter. The Appendices include interview guides, focus group guides, guides for the RWH site assessments, and the procedure adopted to test water quality. This is so that the research could be replicated if needed.

Ensuring reliability of qualitative results can be challenging but can be accomplished by ensuring data collection processes are transparent and dependable. The procedures to develop the water security framework and to mitigate researcher bias are presented in Chapter 4. Both the codes and the coding process that was used to analyse the findings from the stakeholder interviews are presented, and the stakeholder interview guide can be found in Appendix I.

2.8.2 Validity

Creswell & Creswell (2018, p. 200) recommend that validity strategies should be actively incorporated into research design. Validity is concerned with the integrity of the conclusions that are generated from research and refers to the appropriateness of the measures used, accuracy of the analysis of the results and generalisability of the findings (Saunders, Lewis & Thornhill, 2015 p.202).

Internal validity is established when research accurately demonstrates a causal relationship within a case study (Yin, 2018, p.45). External validity is concerned with the generalisability of a study and its findings (Yin, 2018, p.45). Threats to external validity arise when the researcher generalises beyond the groups in the study.

The intention of this study was not to generate generalisations about community water security, but instead to contribute to an understanding of water security by analysing a specific case study region. As a result, findings from the case studies are discussed only in the context of the groups involved in the study.

Methods to improve the validity of a study include triangulation and member checking. Triangulation involves using different data sources and methods of collection, which can help to build a coherent justification for themes (Saunders, Lewis & Thornhill, 2015 p.203). One of the benefits of a mixed-methods approach is the opportunity to triangulate multiple sources of data. For the case study, data collected through interviews was triangulated with data collected through focus group discussions. The aim of this was to establish common themes between multiple community participants.

'Member checking' can also be used to determine the accuracy of findings. It involves taking final descriptions back to participants. With the development of the water security framework, select stakeholders were sent the final iteration of the framework and asked to comment on how accurately it represented their understanding of water security in a community context.

2.8.3 Researcher Influence and Bias

During all interviews conducted for this research, steps were taken to ensure that interviewees felt confident in the statements they were making, without feeling the need to agree with the interviewer. The interviewer sought open-ended responses and provided minimal prompts. The intention was to minimize researcher influence on the interviewees.

2.9 Ethical Considerations

In a study such as this one that involves human participants in vulnerable communities, ethical considerations were carefully considered. The University of Cambridge's Code of Ethics was followed. Prior to each of the three field visits and the stakeholder interviews, ethical approval was granted by the Department of Engineering Ethics Review.

Both ethical and cultural sensitivity in cross-cultural studies such as this one, are essential for the protection of the study participants. As Creswell & Creswell (2018) note

> *'Researchers need to protect their research participants; develop a trust with them; promote the integrity of research; and guard against misconduct and impropriety that might reflect on their institutions' (Creswell & Creswell, 2018, p. 183)*

Of particular importance to the researcher was establishing a good relationship with the communities prior to any formal data gathering taking place. In an attempt to ensure the communities that took part in this study felt comfortable with the researcher, community familiarisation was prioritised prior to data collection and a 'repeat-visit' approach was adopted to ensure a good rapport with study participants. The researcher established contact first with in-country NGO partners (Afrinspire and the Kigezi Diocese Water and Sanitation Project), and then through these partners, was introduced to communities to which the research questions were relevant. Communities were specifically selected for their willingness to participate and the appropriateness of the community to study the research questions.

Prior to the start of each interview and focus group, the research aims, and goals were discussed with each participant. Permission to carry out and record the interviews was given in writing, or verbally where participants could not write, and interviewees were given the opportunity to withdraw from the interview at any time. No interviewee chose to withdraw. In order to protect the anonymity of research participants, only interviewee codes and 'roles' were used during the write up of the thesis. All data was stored on the University of Cambridge's OneDrive system and was password protected.

2.10 Chapter Summary

In this chapter, pragmatism has been introduced as the philosophical underpinning that guides this research project. Pragmatism favours methodological pluralism, and so a mixed-methods approach has been adopted to answer the main research question. An abductive strategy of enquiry, where the researcher moved back and forth between theory and data led to three field visits to Uganda over a period of eighteen months. These included a scoping study visit, where interviews were carried out to choose the RWH sites that would be included in the next stage of the research and to answer sub-question (1) *how can the concepts associated with water security be framed to assess the sociotechnical outcomes of rainwater harvesting use in Uganda?* A rainy season and a dry season field visit followed where ten RWH sites from an urban community and ten RWH sites from a rural community in Uganda were assessed against the water security goals that had been identified through the development of a water security framework. The development of this framework was informed by findings from semi-structured interviews with water practitioners.

The specific methods used to answer research sub-questions (2) *to what extent have specific rainwater harvesting interventions met sociotechnical water security goals in Ugandan communities?* and (3) *how do the drivers and barriers of RWH use differ between urban and rural communities in Uganda?'* were presented. These were the methods employed in the rainy season and dry season field visits and included site assessments and field notes, sanitary surveys, end-user and key informant interviews, focus group discussions, water balance modelling and remote water quality tests. Finally, in this chapter, measures to ensure the reliability and the validity of the study were presented along with steps to mitigate the impacts of researcher influence and bias on study participants. Ethical considerations and the measures taken to ensure that study participants felt comfortable with the researcher were also discussed.

3 LITERATURE REVIEW

The aim of this literature review was to identify research gaps related to the topics of water security and rainwater harvesting in the context of low-income countries. In addition, the literature review helped to sharpen the research questions, and ensure they were relevant, insightful and could contribute in a novel way to the current research on rainwater harvesting and water security.

This section reviews how water security has been defined, framed and assessed by scholars. The types of methodologies that have been adopted by other scholars to assess rainwater harvesting using water security tools are discussed, and the socio-technical constraints on rainwater harvesting projects for populations in resource-limited settings are explored.

3.1 Literature Review Technique

The literature search was carried out using Scopus, ScienceDirect, the Cambridge University Library catalogue and Google Scholar. Peer-reviewed publications were sought out using combinations of keywords including: ‘water security’, ‘rainwater harvesting’, ‘climate change adaptation’, ‘water security and rainwater harvesting’, ‘rainwater harvesting and climate change’, ‘water security indicators’, ‘water security frameworks’, and ‘optimisation of rainwater harvesting systems’. In addition, non-academic water security literature from WASH NGOs was reviewed.

Key review papers that summarise the basic concepts and understanding of water security and rainwater harvesting formed the starting point of this literature review. The authors of these review papers and their citations were followed up to deepen the search. In addition, relevant academic journals including the Journal of Water Security, the Journal of Water and Climate Change, the Journal of Water Policy and the Journal of Water, Sanitation and Hygiene for Development were continually monitored to identify new literature relevant to the topics of water security and rainwater harvesting. These journals were selected as they had a high number of publications on the two topics.

A literature map is presented in Figure 5 to provide an illustration of existing research and to logically present the most relevant literature identified through this literature review. A total of 98 full-text papers that referred to water security were reviewed. Within the water security literature, initially papers that covered basic concepts, definitions and metrics of water security were reviewed. This led to the identification of indicator and framework approaches which have been frequently adopted by scholars, multinationals, and NGOs to assess water security. Papers that had specific focus outside the scope of this thesis topics were not included in this review. For example, in 2020, a number of papers linking COVID-19 and threats to water security were published but were not deemed relevant to this topic of study.

A total of 85 full-text publications that assess rainwater harvesting and its role in achieving water security were reviewed. Texts that focused on the adoption of RWH in high-income countries such as the USA were not included in the review, as the socioeconomic conditions were considered to differ substantially from sub-Saharan Africa.

Assessments of rainwater harvesting using water security metrics and goals broadly fit into two categories: socio-technical assessments, and quantitative assessments that analyse whether rainwater harvesting can provide enough water to meet household demand based on simple water balance models. These quantitative assessments typically use a narrow definition of water security (whether water supply meets demand). Socio-technical assessments look at the environmental, political, economic, social and technical challenges associated with the implementation and adoption of rainwater harvesting systems.

The intersection between the two research areas occurs when scholars have used water security frameworks to examine the contribution of rainwater harvesting to water security. In this literature review, few publications were found that focus on how framings of water security can be used to assess the sociotechnical challenges and opportunities associated with the adoption of RWH in low-resource settings. In Figure 5, a literature map is presented that demonstrates the progression of the sub-topics that were covered within the literature review. For each sub-topic within the literature review, the most relevant publications that were reviewed are presented.

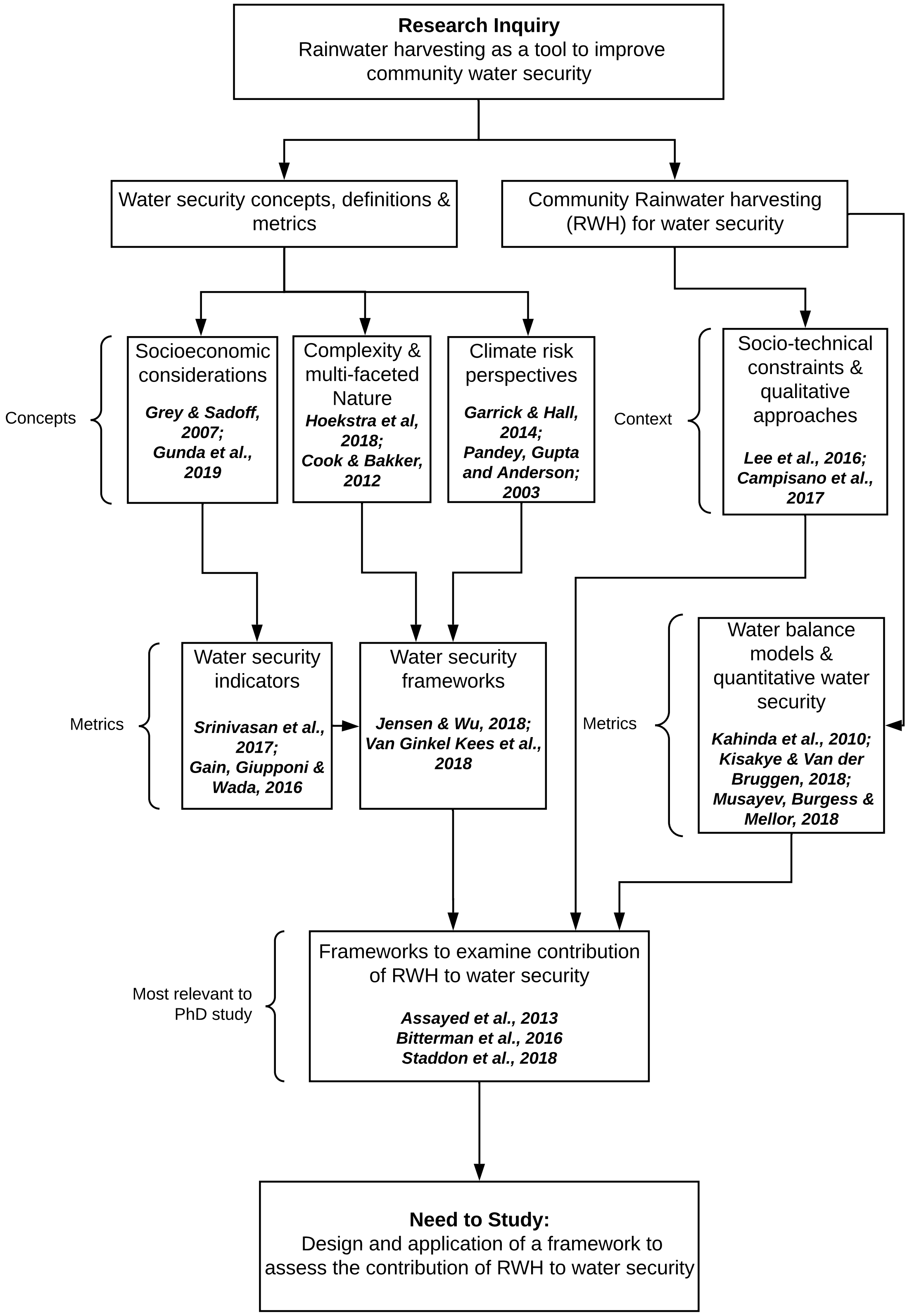


Figure 5 - Literature review sub-topics and research enquiry process

3.2 Understanding Water Security

In 2012, Cook & Bakker (2012) published what they believed to be the first review of its kind – a critical analysis of the differences and commonalities in approaches to water security across academic disciplines. Their review highlighted that the concept of water security had become increasingly popular over the previous two decades. Nonetheless, eight years later, there is still no clear consensus on the definition of water security. Framings of water security are diverse. While early definitions focused solely on water quantity and availability, more recent framings include a multitude of factors ranging from ecological considerations, governance, water quality, human health and climate limitations (Gunda et al., 2019).

Table 6 presents four of the most frequently cited definitions of water security according to a 2018 review carried out by Gerlak et al. (2018). Despite a lack of consensus on the definition of water security, the well-known and accepted definitions in Table 6 share similarities. Common themes that run through the four definitions include, water for humans, protection of the environment and mitigation of water-related risk.

Source	Definition
Global Water Partnership (2000)	"Sustainable use and protection of water resources, safeguarding access to water functions and services for humans and the environment, and protection against water-related hazards"
Grey & Sadoff (2007)	"The availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risk to people, environments and economies"
Bakker (2012)	"Acceptable level of water-related risks to humans and ecosystems, coupled with the availability of water of sufficient quantity and quality to support livelihoods national security, human health and ecosystem services"
UN-Water (2013)	"Capacity of the population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human, well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability"

Table 6 - The most commonly cited definitions of water security according to Gerlak et al. (2018)

Several scholars refer to water security as a status (Abedin, Habiba & Shaw, 2013 pp. 7) and others refer to it as a goal (Global Water Partnership, 2000). In recent years, however, water security has been viewed as a modern framing to help identify the social, environmental and technical challenges associated with water provision (Vörösmarty *et al.*, 2010). There is agreement among scholars that, broadly, framings of water security encourage the use of water to increase economic welfare, to enhance social equality, to move towards long term sustainability and to reduce water-related risks (Hoekstra, Buurman & Ginkel, 2018). Nonetheless, Cook & Bakker (2012) point out that the meaning of water security varies dramatically between disciplines.

Cook & Bakker (2012) explain that within the engineering sector, the focus of water security is on protection against water-related hazards such as floods, droughts and conflict, and on ensuring that water supply satisfies demand. Within environmental studies, research into water security focuses on access to water functions for humans and the environment. In contrast, social scientists concentrate on water security as a way to improve human health, minimise vulnerability to hydrological variability, and to ensure sustainable development.

Hoekstra, Buurman & Ginkel (2018) agree that there are multiple perspectives on water security. Water resources studies focus on water scarcity and water supply and demand management. Environmental studies focus on the access to water function and water availability in terms of quality and quantity. Policy studies emphasise interdisciplinary linkages such as climate, energy and economy, as well as the sustainable development of water resources (Hoekstra, Buurman & Ginkel, 2018). Political perspectives also focus on equity, conflicts over water, governance, institutional arrangements and water rights and ownership. These divisions on water perspectives are represented in Figure 6.

Image of water security perspectives removed for copyright reasons. Copyright holder: Hoekstra, Buurman & Ginkel.

Figure 6 - The various perspectives on water security depending on the discipline from which the topic is approached. Source Hoekstra, Buurman & Ginkel (2018)

Hoekstra, Buurman & Ginkel (2018) believe that the vernacular adopted by water professionals to define the human relationship with water has evolved over recent years. Several different terms have been used to describe the complex relationship between water access, management of water services and socioeconomic development. It is important to understand how water security differs from these other terms - water scarcity, water stress, water poverty and integrated water resources management.

Water scarcity is a term used to describe the relationship between demand for water and its availability (Casey, Carter & Yeo, 2012). Physical scarcity exists when localised water resources are overexploited. Socioeconomic water scarcity exists when efforts to keep up with demand for the resource are insufficient. This can be due to a lack of financial resources, institutional support or political will. Socioeconomic water scarcity is a consequence of poor governance rather than a lack of absolute availability.

Water stress is viewed as the outcome of water scarcity and can manifest itself as poor access to water of good quality, poor health, conflict over water resources or crop failure (Casey, Carter & Yeo, 2012). Water stress does not just affect populations that suffer from physical water scarcity (Qadir *et al.*, 2007), it can be the consequence of a lack of infrastructure to provide access, or of persecution preventing certain groups from accessing water technologies.

The term water poverty is defined as '*a situation where a nation or region cannot afford the cost of sustainable clean water to all people at all times*' (Feitelson & Chenoweth, 2002). Water poverty focuses specifically on the cost and affordability of water.

When the term ‘integrated water resources management’ (IWRM) was first adopted by scholars, it reflected a need to address water systems in a more holistic manner. Surface water and groundwater resources are linked, and water management was in need of a systems approach. IWRM has been the dominant paradigm for water management for several decades (Bakker & Morinville, 2013). Nevertheless, it has been criticised for failing to provide comprehensive solutions to the range of complex issues associated with water resources management (Aboelnga *et al.*, 2019).

Water security shares key concepts in common with IWRM such as the focus on equitable management of water resources and sustainability of ecosystems. However, the progression of research focus from water poverty or integrated water resources management towards ‘water security’ is representative of the intention of the water policy community to capture the broad number of factors that put water access at risk. Gerlak *et al.* (2018) believe that the range of water security definitions and framings suggest that academics from multiple disciplines have identified the importance of reliable water access in achieving all of the UN’s Sustainable Development Goals.

3.3 Water Security Characteristics

As definitions of water security have evolved, a variety of characteristics has been added to the discourse. Early definitions focused on physical attributes of water security with ‘*availability’*, ‘*acceptable quality’*, ‘*adequate quantity’* and ‘*affordability’* referenced regularly (See Table 7). These four parameters have come to be viewed as the benchmarks for evaluating water security. Other definitions have introduced more nuanced attributes such as ‘*water that enables livelihood generation*’ (Grey & Sadoff, 2007), ‘*sustainability*’ (UN-Water, 2013), ‘*ecosystems*’ (Bakker, 2012) and ‘*risk/resilience’* (Hoekstra et al. 2018).

Table of water security attributes removed for copyright reasons. Copyright holder: Gerlak et al.

Table 7 - Attributes associated with prominent definitions of water security. Source: Gerlak et al. (2018)

The following attributes are the dominant characteristics found in the water security literature (Cook & Bakker, 2012; Gerlak *et al.*, 2018; Hall & Borgomeo, 2013; Hoekstra, Buurman & Ginkel, 2018).

3.3.1 Availability and Quantity of Water

Cook & Bakker (2012) find that earlier framings of water security focused heavily on availability and quantity as the core components of water security. These framings were often linked to assessments, most likely because availability and quantity of water are quantifiable and easily measured. Scholars from the environmental sciences often refer to availability with reference to minimising the impacts of hydrological variability. This is particularly appropriate for geographic regions that do not have evenly distributed rainfall patterns across the year (Hoekstra, Buurman & Ginkel, 2018).

Availability of water is linked to quantity through sufficiency of water supply (Cook & Bakker, 2012). Whether the supply of water meets the population's demand is a key determinant in water security. This 'demand' is defined by WaterAid as '*meeting basic human needs to prevent dehydration, with enough water for cooking bathing, sanitation and hygiene*' (Casey, Carter & Yeo, 2012). There is no global consensus on the minimum volume of water required but the World Health Organization (WHO) recommends that minimum water usage should be 20 litres/person/day and the optimal quantity for domestic use is 100 litres/person/day (WHO, 2012).

In reality, in the lowest income countries, the amount of water collected from improved water sources tends to be less than the WHO recommends (Casey, Carter & Yeo, 2012). Along with geophysical location, infrastructure also has an influence on water availability. Reliable infrastructure systems should provide populations with the right quantity of adequate quality water at the required pressure (Aboelnga *et al.*, 2019). However, low availability of water is often linked to a lack of infrastructure, rather than to a lack of ground or surface water.

The UN human right to water specifies that water supply must be sufficient and continuous (UN-Water, 2010). The role of physical infrastructure is to reliably ensure the right quantity of water is delivered to populations. In unreliable systems, water shortages often occur as a result of failures of a system's physical components. In many cities in developing countries, water shortages are still a daily occurrence, interrupting income-generating activities, increasing the likelihood of contamination and eroding trust in public water supply (Aboelnga *et al.*, 2019). In response, decentralised water services are used to plug the gap. Additionally, diversity of water resources is key to achieving water security, as it mitigates the risk of dependency on one water source and secures alternative sources to meet demand (Aboelnga *et al.*, 2019).

3.3.2 Acceptable Quality Water for Good Health

Table 7 demonstrates that 'water quality' is the attribute most frequently associated with water security. The prevalence of water quality in the narrative reflects the importance of good quality water for human well-being. Grey & Sadoff (2007) refer to 'acceptable' quality of water, Bakker (2012) refers to 'adequate' quality and the Global Water Partnership (2000) references 'safe' water. While water quality can be measured by a multitude of metrics (total dissolved solids, the number of thermotolerant coliforms present, pH, turbidity etc.), the specific contaminants that are measured in water security studies often depend on an evolving understanding of their health impacts (Gunda *et al.*, 2019).

When the terms 'acceptable', 'adequate' and 'sufficient' are used, the question must be asked; acceptable to whom? Scholars and practitioners typically use the World Health Organization's (WHO) 'Drinking Water Quality Standards' as a benchmark for acceptable water quality, but 'acceptable' to the user is equally as important as physiochemical and microbiological metrics. A common example of divergence between WHO standards and end-user's 'acceptance' is standards for the level of chlorine in drinking water (WHO, 2008). The WHO recommends a free residual chlorine level of 0.5mg/l. However, studies have shown that at this value, users are deterred by the taste of the chlorine (Francis *et al.*, 2015).

Gunda *et al.* (2019) argue that not all water for human use needs to be treated to drinking water standards. Instead, they encourage point-of-use (POU) water treatment such as chemical or solar disinfection, boiling and reverse osmosis. The rationale behind this is that to maintain drinking water standards is expensive, energy intensive and often laborious, requiring resources that are frequently unavailable in rural settings.

WaterAid offer a broader interpretation of the required water quality for water security, explaining that *'no significant health risk should arise from [the] use'* of water and that *'contaminants should not exceed the broadly accepted water quality standards'* (Casey, Carter & Yeo, 2012). In developing countries, risks to water quality often arise after the point of collection, through poor hygiene practices or dirty containers (Casey, Carter & Yeo, 2012). It is for this reason that when viewed through the lens of water security, a holistic framework, water quality standards are often less strict than those that would be applied on a national level. This is reflected by the subjective language used to describe water quality.

3.3.3 Livelihoods and Productivity

Grey & Sadoff (2007) believe that water security is so essential to socioeconomic development that sustainable growth and poverty eradication cannot be achieved without reducing water's destructive potential and increasing its productive potential. In low-resource settings, the time and energy dedicated to fetching water affects people's ability to work, farm or attend school (Casey, Carter & Yeo, 2012). There is strong evidence to suggest that better access to clean water reduces the prevalence of water-related diseases that inhibit populations' ability to work and generate revenue from livelihoods (van Ginkel Kees C. H. *et al.*, 2018).

Framings of water security that lean towards the anthropocentric over the environmental have approached water security as a subset of food security, a term that has been more widely adopted by sustainable development scholars. The Food and Agriculture Organisation (FAO) link water security to agricultural endeavours, particularly relevant to communities in sub-Saharan Africa, where the majority of the population generates income from agricultural practices (FAO, 1996).

The inclusion of economic growth and livelihoods in the water security literature is indicative of the strong relationship between water access and socioeconomic development. Casey, Carter & Yeo (2012) explain that there are links between water for basic human needs and water for livelihoods:

> *'If people do not have ready access to clean water, the time and energy required to fetch water, coupled with the negative health impacts of water-related diseases, affects their ability to farm and work. In turn, revenue generated from livelihoods can help to fund the ongoing maintenance of water sources, ensuring continued access to the resource'.*

3.3.4 Equitable Access

Van Ginkel Kees C. H. *et al.* (2018) believe that water security is about increasing welfare for all in the long-term. The emphasis here is on the 'all' because water insecurity disproportionately affects particular groups such as the poor, the rural or the persecuted (Grey & Sadoff, 2007). Regions at risk of significant climate variability or water stress have obvious motivation to focus on water security. The term is of less use in countries that are deemed to be ‘water secure’, where there are reliable freshwater resources, robust infrastructure and long-standing institutions to support water delivery.

Wealthy nations can offset low water availability by investing in high-cost water management techniques such as desalination or inter-basin water transfers. These solutions are too expensive to apply in low-income countries, where there is often not the institutional capacity to realise such large-scale projects. Water scarcity exists in countries that span the socioeconomic scale; however, the consequences are often most severe for populations in the world’s least developed countries.

Abedin, Habiba & Shaw (2013 pp.10) believe that in South Asia, sub-Saharan Africa, Latin America and Oceania, water insecurity is a problem of social and physical barriers preventing equitable access to water. Gunda *et al.* (2019) agree that as global dynamics of population growth and climate change influence the state of water resources, recognising the ‘*nexus of water quantity, water quality and societal factors’* becomes increasingly important in order to assess water security in an integrated manner.

One subset of equitable access is pricing and affordability of water services. Water service fees that cover the financial costs of centralised water provision are essential. Firstly, because pricing of water provides users with a notion of the value of water, which in turn, reduces overconsumption and misuse (Aboelnga *et al.*, 2019), and secondly, because revenues from tariffs provide funding for infrastructure repairs and water resources protection. Nonetheless, the price of centralised water services has been cited as the most significant deterrent to urban users. As a result, in developing countries, illegal use of water from centralised systems represents one of the major socio-economic threats to urban water security (Aboelnga *et al.*, 2019).

3.3.5 Effective Management and Institutional Support

Effective governance is typically high up on the agenda of water security studies of all scales: community, local, national and transboundary (Gerlak *et al.*, 2018). However, Bakker & Morinville (2013) explain that there has been relatively little research into the governance dimensions of water security. Investments in water infrastructure and institutions that support the delivery and maintenance of water supply are essential to achieve water security (Grey & Sadoff, 2007). When discussing water governance, IWRM is still the most widely adopted framework for managing water systems. Bakker & Morinville (2013) believe that water security perspectives can contribute to the dialogue, as they also emphasise the inherent uncertainty in the management of complex socio-ecological systems. Jepson *et al.* (2017) go one step further, asserting that assessments of water deficiencies among low-income populations are increasingly being reframed from IWRM to water security.

The importance of good governance at all scales has been noted by several scholars (Garrick & Hall, 2014; Srinivasan, Konar & Sivapalan, 2017), not just within the water security literature. Good governance, and management of water systems are viewed as the cornerstone of successful WASH projects. Governance exists at all scales, from increased participation of water users in the financing and management of water services to transboundary cooperation in the management of water resources. Institutions, such as the Ministry of Health, Ministry of Environment, faith-based organisations, NGOs and private corporations should coordinate this governance so that water services can be maintained (and indeed improved) over the long-term. Debate over the scale at which governance is most effective for optimal water management is ongoing. The Global Water Partnership explain:

> *'Water governance is the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society. [It]is more than just good government. It works through networks and relationships between government, the public, private and voluntary sectors, community groups and citizens themselves' (Global Water Partnership, 2007)*

Encompassing financing, decision-making and policymaking, one of the most significant challenges in the WASH sector has been the 'messy middle' between national policymaking and local practices. In several developing countries, where governments do not have the resources to fill this gap, NGOs take up the role of bridging this 'messy middle' (Cleaver & Franks, 2007).

On a community scale, water committees offer a common management structure, particularly in rural communities. However, there is robust evidence to suggest that the artificial creation of committees, set up with the specific goal of managing water resources, fails to ensure the sustainable management of water resources (Whaley, Cleaver & Mwathunga, 2021). At a community level, Whaley, Cleaver & Mwathunga (2021) suggest 'working with the grain' by identifying and working with existing institutions, practices and knowledge systems. The Kigezi Diocese Water and Sanitation Project have adopted this 'working with the grain' approach in the management of community rainwater harvesting systems in Uganda. Identifying that artificially created water committees have not delivered the desired results of long-term upkeep and management of water systems, they now approach existing organisational bodies such as women's groups (KDWSP, 2020).

A further criticism of the voluntary committee approach is that, particularly when attempting to engage women in the management of water, rather than empowering them, voluntary committees burden women with a further form of unpaid labour, where they are already charged with the majority of domestic chores within the home, particularly in sub-Saharan Africa (KDWSP, 2020).

Under a water security framing, good governance can be articulated as '*the system of actors, resources, mechanisms and processes which mediate society's access to water'* (Cleaver & Franks, 2007). Good governance drives effective management of water services, which is only possible with continued institutional support at all scales. Communication between stakeholders at each scale is vital for water security.

3.3.6 Sustainability

'Sustainability' is a wide-ranging notion with multiple interpretations (Marques, da Cruz & Pires, 2015). Scholars have pursued two divergent pathways when linking water security to sustainability. The first is when water security is viewed as a means to contribute to the core concepts associated with sustainable development and the United Nations' Sustainable Development Goals. For example, the Global Water Partnership uses the economic, social and environmental concepts associated with sustainable development to define water security as a term which means that:

> *'every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring the natural environment is protected and enhanced' (Global Water Partnership, 2000).*

Sustainable Development Goal 6 aims to 'ensure the availability and sustainable management of water and sanitation for all' (United Nations, 2015). Within this goal, targets include (6.1) ensuring universal and equitable access to safe and affordable drinking water, (6.3) improving water quality by reducing pollution, (6.4) reducing the number of people suffering from water scarcity by ensuring a sustainable supply of freshwater, (6.5) implementing IWRM at all levels, (6.6) protecting ecosystems and, crucially, (6.a) expanding capacity-building support to developing countries in WASH activities and (6.b) strengthening local communities in improving WASH management (United Nations, 2015).

Many of the concepts associated with water security are embedded in the SDG 6 targets. Gain, Giupponi & Wada (2016) believe that success in achieving the SDGs will depend on how well progress towards the goals can be tracked, and so methods to assess water security will be integral to achieving not just SDG 6, but all of the Goals. Similarly, Adeel (2017) argues that water security is crucial to the success of the entire suite of SDGs.

The second approach has been to link water security to the sustained provision of water supply over the long-term, where 'sustainability' is synonymous with 'longevity'. This approach is common among the WASH literature, and has links to affordability of services and the capacity of institutions and populations to maintain water-systems and services over the long-term (James & Shafiee-Jood, 2017). Both the affordability and ease with which RWH systems can be maintained have been identified as barriers to the adoption of RWH in developing countries (Campisano *et al.*, 2017). Nonetheless, when

RWH systems are designed using locally available materials, systems can be repaired and maintained by homeowners themselves. This, however, relies on capacity-building support as recommended by SDG Target 6.a (Dismas, Mulungu & Mtalo, 2018).

3.3.7 Risk and Resilience

Water security is dynamic; a community cannot be deemed to be water secure indefinitely as there is always the threat that unforeseen risks will lead to a renewed state of insecurity. For example: sudden political instability, lengthy drought and flash floods can all destabilise water security within a matter of days. In response, attributes such as robustness and resilience have become popular guides for the design of water services to overcome future uncertainty (Butler *et al.*, 2017). Hall & Borgomeo (2013) view risk management as a core activity associated with ensuring water security, defining water security as water access with a '*tolerable level of water-related risks'*. Similarly, Abedin, Habiba & Shaw (2013 p.7) believe that water secure populations have the ability to cope with those uncertainties and risks associated with water-related hazards such as floods and droughts.

Many of the risk perspectives address those threats associated with the impacts of climate change, such as higher climatic and hydrological variability and changes in water quality and quantity (Hoekstra, Buurman & Ginkel, 2018). Hydrometeorological disasters are most likely to impact populations in low-resource settings, affecting food availability, the political stability of fragile states and deepening the vulnerability of rural communities that depend on rain-fed agriculture for food and income. A person living in a developing country is 150 times more likely to be affected by disaster than a person living in wealthier nations. This is, in part, caused by the higher risks associated with the geophysical location of developing nations, but also because many cities in low GDP countries suffer from a lack of adequate infrastructure to protect populations (ODI, 2014).

As a percentage of GDP, economic losses in the face of a disaster can be 20 times greater in developing countries than high-income countries (Cambridge Centre for Risk Studies, 2015). In sub-Saharan Africa, variability in rainfall patterns, characterised by frequent and severe droughts, heat waves and floods, is having a direct impact on both water and food security, impacting economic growth and the livelihoods of the poor (Kiggundu & Wanyama, 2018).

There is agreement that good water security can reinforce resilience to the impacts of climate change, but strategies to deal with the uncertainty associated with climate threats need to move '*beyond infrastructure'* to include governance and social learning as key strategies for effective water management that builds resilience in target populations (Bakker, 2012).

In the context of infrastructure systems, resilience refers to a system's ability to bounce back after shock, stress or failure. Renschler et al. describe resilience as:

'A function indicating the capability to sustain a level of functionality, or performance, for a given building, bridge, lifeline network, or community, over a period defined as the control time' (Renschler et al., 2005).

If supplementing an alternative source of water, the presence of on-site RWH allows a household or community to be more resilient to interruptions in water service by providing a secondary water source, and therefore providing redundancy in water supply. Whether RWH systems can return to service rapidly after disruption – e.g., caused by a faulty part, depends on the availability and affordability of system components and the capability of users to carry out repairs. As with the sustainability of RWH systems, resilience is more likely to be achieved if components can be sourced locally for an affordable price. The relative simplicity of RWH (no moving or mechanical parts) means it is a technology that is appropriate for even remote, rural users, as components such as leaf filters can be constructed from widely available products including buckets and wire mesh.

3.3.8 Protection of Ecosystems

Of the 124 publications reviewed by Gerlak *et al.* (2018), no study dealt solely with water security in the environment. Instead, the majority of publications took an anthropocentric view of water security, with several neglecting ecosystems altogether. Reference to ecosystems tends to occur within the context of water security studies that are carried out on a transboundary scale. These studies often focus on freshwater resources and the geopolitical implications of water pollution across national borders. At the community scale, the majority of studies focus solely on human water uses (Gerlak *et al,* 2018). Spanning the anthropocentric-environmental divide, Aboelnga *et al.* (2019) view ecosystems as natural infrastructure that is critical to people's wellbeing and livelihoods, noting that the preservation of ecosystems is in humanity's interest.

Uniquely, Vörösmarty *et al.*, (2018) view ecosystems as an integral building block of water security, and therefore sustainable development as a whole. Many of the problems associated with water insecurity such as water scarcity, pollution and lack of clean drinking water, stem from the absence of adequate environmental management (Vörösmarty *et al.*, 2018).

They argue that protection of ecosystems should not be an addendum to the socioeconomic goals typically found in the water security literature, but instead should be at the forefront of the socio-hydrological relationship. The environmental costs associated with the exploitation of water resources such as depletion of reservoirs, the cost of energy for water treatment and the pollution of rivers from pesticides are all critical threats to water security at any scale.

3.4 Assessments of Water Security

Human-water systems have traditionally been viewed through the lens of physical 'water scarcity', either demand-driven 'water stress', or population driven 'water shortage' (Gain, Giupponi & Wada, 2016). Supply-driven scarcity is measured by calculating per capita availability of renewable freshwater resources and demand-driven scarcity is measured by calculating the ratio of estimated annual freshwater demand to availability (Gain, Giupponi & Wada, 2016). Water security is a multi-faceted problem that goes beyond the traditional balancing of water supply and demand. With its more nuanced characteristics, water security is more challenging to measure, as many of the attributes (such as effective management of water systems) associated with good water security are not easily quantified.

3.4.1 Water Security Indicators

Popular among water security scholars is the use of indicators to represent, measure and communicate progress towards water security. According to Jensen & Wu (2018), indicators function to support evidence-based policy making to encourage water security by condensing complex phenomena into easily communicable quantitative indicators. Before the widespread adoption of the term water security, an indicator approach was initially used to assess water poverty. Water poverty assessments such as the Water Poverty Index created by Sullivan (2002) and the Water Poverty Index by Perez-Foguet & Gine (2011) generated a set of composite indicators, with a significant focus on ground and surface water availability.

In 2000, the Global Water Partnership (GWP) developed one of the first set of indicators to specifically assess water security, believing that a 'target' and 'indicator' approach has the potential to improve water resources management at the local, national and international scale (Global Water Partnership, 2000). The GWP argued for a universal set of water security targets to be supported by clear definitions and indicators, stating that:

> *'targets, milestones and indicators are vital to boost water's political visibility, assist the mobilisation of funds, and enable programme outputs and impacts to be monitored' (Global Water Partnership, 2000).*

These indicators were used to promote a more tangible understanding of what water security means by providing an opportunity to assess the extent to which each target was being achieved in different locations (Global Water Partnership, 2000). The GWP's indicators included:

- Meeting basic needs
- Securing food supply
- Protecting ecosystems

- Sharing water resources
- Managing risks
- Valuing water
- Governing water wisely

Debate about whether the introduction of indicators and metrics is counterproductive to achieving targets exists outside of the water security dialogue. Campbell's Law from 1979 cautions that

> *'the more any quantitative indicator is used for social decision-making, the more apt it will be to distort and corrupt the social pressures it is intended to monitor' (Campbell, 1979).*

Indicators are viewed as a tool to achieve results. However, the issue with indicators is that they can force stakeholders to ignore other metrics that are not included in the 'indicator list'. Garrick & Hall (2014) agree that water security indicators are subject to '*all of the same conceptual and methodological issues associated with indicators more generally'*, such as problems with complexity and causality and a lack of comparable data. On the other side of the debate, Howlett & Cuenca (2017) find that although water security indicators have their limitations in depicting the complexity of the topic, their ease of use and interpretation are of value when setting goals for policymaking. Dickson, Schuster-Wallace & Newton (2016) agree that indicators provide useful assessment tools because they simplify the modelling process and provide results in an accessible format.

With indicators, there is an obvious trade-off between simplicity in communicating the critical issues associated with water security and capturing the complexity and nuance of water security concepts. In 2013, Norman *et al.* developed the Water Security Status Indicators (WSSI) assessment method that focuses on water quality and quantity. The WSSI were designed to be implemented at a local scale and were used to assess the water security status of a community in British Columbia, Canada at one point in time. The output was a simple tool that a community could use to assess the quality and quantity of water, but just as with other indicator approaches, the WSSI were criticised for failing to capture the interaction between the factors that impact water security.

The WSSI methodology included end-user participation and stakeholder engagement so that water security indicators could be tailored to the goals of the community in question. This approach meant that the tool was designed specifically for use by communities, enabling them to recognise, articulate and address the links between their water security status and existing water governance practices (Norman et al., 2013).

3.4.2 Water Security Frameworks

Water security frameworks, which serve to structure the concepts associated with water security, are tools that enable stakeholders to identify which outcomes of water projects should be prioritised. Researchers from different disciplines take varying approaches to developing water security frameworks and, indeed, the conclusions drawn on whether a target population is 'water secure' are highly dependent on the initial framing of water security.

There is no agreed-upon understanding of how to measure water security, and different framings represent different priorities for the assessment of water security. For example, some framings focus on measuring and managing water-risks, whereas others focus on the development of water resources to meet human needs (Aboelnga *et al.*, 2019).

In recent years, frameworks have superseded indicators in the assessment of water security. The fundamental goal of water security indicators is to *measure* progress towards water security, whereas frameworks provide a structure to *assess* progress towards water security. The benefit of developing a framework to assess water security is that it allows for the complexity of the interacting components of water security to be mapped. Frameworks encourage assessment rather than measurement of water security, allowing the challenges and opportunities to achieving water security to be readily identified. Scholars who have adopted this approach argue that this enables a more comprehensive picture to emerge of water security (Mason, 2013).

Frameworks have been used to communicate and assess the concepts associated with water security. In Table 8, a summary of prominent indicator and frameworks for the assessment of water security is presented. While there is now a wealth of frameworks, Cook & Bakker (2012) point out that there is a gap in the operationalisation of these frameworks. For this reason, they argue that new frameworks should be developed with a specific location of application in mind, and with a narrowing definition of water security, so that the water issues of relevance can be focused on.

Author	Year	Assessment Type	Scale
GWP	2000	**Indicator:** WS assessed by 7 indicators which help identify whether countries are on track to achieve WS targets	Global
Vörösmarty et al.	2010	**Framework:** WS assessed by 23 stressors, grouped into 4 major themes to create a framework for assessment	Global
Mason	2013	**Framework:** In partnership with the ODI, WS is framed through metrics of scarcity, risk and security	Country
Norman et al.	2013	**Indicator:** By developing the water security status indicators (WSSI) with end-users, the authors provide recommendations for decision-making processes for water security	Community
Lautze & Manthrithilake	2014	**Framework:** WS is assessed by 5 dimensions which include socioeconomic and physical considerations	Global
Gain, Giupponi & Wada	2016	**Framework:** A global water security index (GWSI) is developed by aggregating indicators using spatial MCA methods	Global
Bitterman et al.	2016	**Framework:** A conceptual framework is developed to describe the linkages between indicators. This framework is then applied to the assessment of RWH	Regional
Dickson et al.	2016	**Framework:** A list of 176 indicators of WS is consolidated into a framework specifically for the use of community members	Community
Howlett & Cuenca	2017	**Indicator:** The technical merits and political advantages of water security framings are assessed and a range of WS indicators are developed	Global
Srinivasan, Konar & Sivapalan	2017	**Framework:** WS is framed as an outcome of coupled human-water systems	Global
Jensen & Wu	2018	**Indicator:** Development of indicators for urban WS and these indicators are applied to the assessment of two cities where comparisons are made	City
Aboelnga et al.	2019	**Framework:** Four indicators are used to structure the framework: drinking water and human beings, ecosystem, climate change and water-related hazards to assess urban and peri-urban WS	City
Bagheri & Babaeian	2020	**Framework:** A systems approach is adopted to assess the water scarcity of a region in Iran	Regional

Table 8 - Recent publications involving water security indicators and frameworks arranged chronologically

Several of the authors listed in Table 8 first develop indicators of water security, and then collect further data on the interconnections between the indicators to develop a framework. For example, Srinivasan, Konar & Sivapalan (2017) argue in favour of a coupled human-water system framework rather than an indicator approach to assess water security, critiquing an indicator approach for only providing a snapshot in time with '*no sense in history and no predictive insight',* leaving a 'so what?' question as the output of the indicator model. A framework approach often leads to 'emergent' patterns resulting in surprises that could not have been predicted from the behaviour of individual elements.

Gain, Giupponi & Wada (2016) provide one such example where indicators of water security are identified and then used to develop a spatial multi-criteria analysis framework to provide a global assessment of water security. The framework helps to identify which regions suffer from water insecurity, and which strategies are needed to achieve water-related targets. They state that first, whether there is sufficient quantity of water in a location should be assessed. Next, whether these resources are available, accessible and affordable to society should be analysed. Third, whether the water is of good quality and whether the area is free from flood risk should be reviewed, and finally, whether standards of governance and management support water security should be considered. In this case, indicators have been used to identify researchers' priorities for water security.

Aboelnga *et al.* (2019) focus on urban water security and group water security indicators into four categories – drinking water and human beings, ecosystems, climate-change and water-related hazards and socio-economic. The framework provides simple, quantifiable metrics to assess each component of water security with the aim of assisting policymakers to target scant resources more effectively. Some scholars argue that there is a further need for quantifiable metrics of water security to be developed, so that progress towards the goal of water security can be better understood and communicated (Mason, 2013). This approach however, risks reducing water security to a set of numbers, when much of the original incentive for its adoption was to move away from water itself as the object to be secured to recognising the wider, more nuanced, relations through which water shapes people's lives (Jepson et al., 2017).

Staddon & Scott (2018) believe that the conceptual appeal of water security is tempered by limits to its application. New research should bridge this gap between conceptualisation of water security and using these concepts to assess the delivery of real-world water services, providing insights to help water providers to better deliver projects, and policymakers to create incentives to support the successful delivery of these services. Further empirical fieldwork that improves knowledge of how to apply the multiple dimensions associated with water security in multiple geographic contexts is needed (Staddon & Scott, 2018).

3.5 Scales for Assessing Water Security

The scale at which water security is assessed significantly impacts the type of assessment that is carried out (Jensen & Wu, 2018). Historically, most studies on water security have been conducted at the city, state or national scale. Far fewer studies focus on either the transboundary (larger) or the community (smaller) scale (Bakker, 2012). Van Ginkel Kees C. H. *et al.* (2018) find that few studies assess water security on an urban scale, and there appears to be even less research that compares the water security of populations in urban environments to those in rural environments.

Cook & Bakker (2012) note that academics from different disciplines tend to focus on different scales:

> *'Development studies tend to use national scales, hydrologists often focus on watershed scales from the regional to the national, and social scientists regularly work at the community scale' (Cook & Bakker, 2012).*

Gerlak et al. (2018) find that studies which consider both humans and the environment are more likely to have been conducted at large geographic scales such as the transboundary, national or regional scale. The advantage of assessing water security at a larger scale is that a wider range of influencing factors can be accounted for, such as activities conducted by neighbouring countries. Nonetheless, several scholars encourage assessments of water security to be developed at a local level to reflect the significant variation in water challenges between localities and within a single country (Jensen & Wu, 2018).

Throughout this literature review, several calls for further studies that underscore the importance of incorporating community context to water security studies were identified (Cook & Bakker, 2012; Dickson, 2016; Gerlak et al., 2018; Norman et al., 2013). To factor in this context, special effort must be made to consult, listen to and incorporate feedback from a range of stakeholders. This is achievable on a community scale as typically a narrow group of stakeholders has significant influence on community operations.

3.6 Rainwater Harvesting and Water Security

Scholars have begun to use the lens of water security to assess whether rainwater-harvesting has the potential to provide adequate water of good quality to satisfy user demand. Much of this research though has adopted a narrow definition of water security as simply '*the percentage of time a tank of a given size is empty'* (Haque, Rahman & Samali, 2016; Kisakye & Van der Bruggen, 2018). This is of value when designing and optimising RWH systems. However, further research is needed to better understand the environmental, socioeconomic, and geophysical conditions under which the technology is most likely to be adopted, maintained and of value to the user.

It is critical to distinguish that the rainwater harvesting literature that is of interest to this study is that which places RWH in the context of water security, climate change adaptation and socioeconomic benefit to the user. There is already robust understanding of the optimal design features of rainwater harvesting (Pacey & Cullis, 1986; Thomas, 2000; Andersson *et al.*, 2009; Mohammad *et al.*, 2017). Much research has been carried out on how best to design rainwater harvesting systems to meet demand based on historic rainfall data (Rahman, 2017; Zhang *et al.*, 2018) and on optimising the tank storage volume so that it is compatible with the size of the rooftop in the system (Liaw & Tsai, 2004; Mishra, Adhikary & Panda, 2009).

Figure 7 demonstrates a typical household RWH system. When implemented correctly, RWH can provide good quality water in terms of microbial and physiochemical quality (Parker *et al.*, 2010; WHO, 2008). There are, however, strong links between the quality of water provided by RWH systems and whether the system has been maintained (Rahman, 2017). To date, numerous studies have found that the quality of rainwater is directly related to the cleanliness of catchments, gutter and storage tanks (Abdulla & Al-Shareef, 2009; Baguma *et al.*, 2010; Campisano *et al.*, 2017; Misati *et al.* 2017).

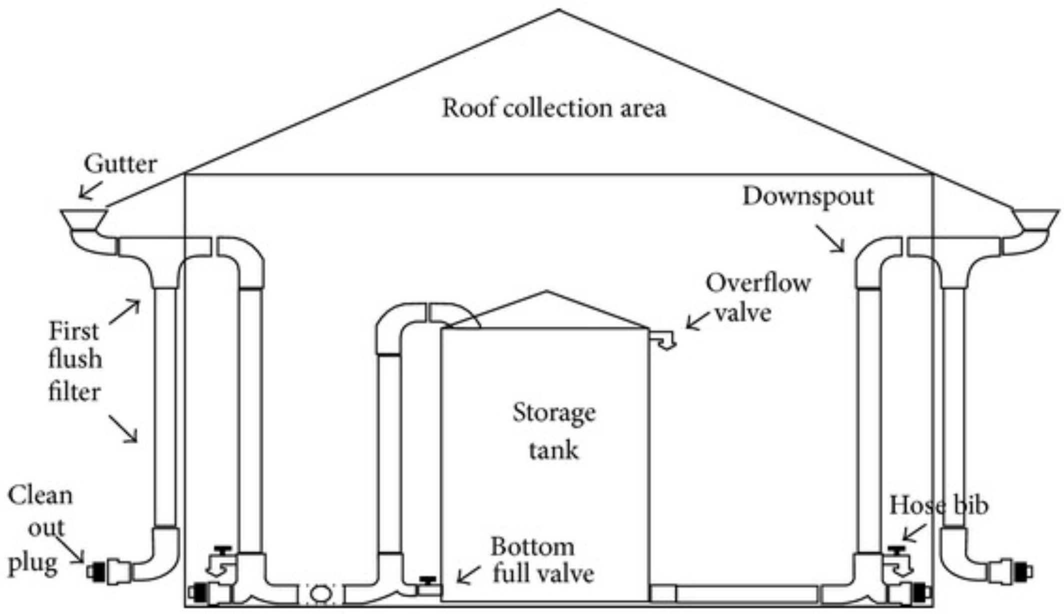


Figure 7 - A typical rainwater harvesting layout. Household storage ranges from 2000 - 10,000 litres typically. Source: Rahman *et al.* (2014)

Several scholars have researched the impact that climate change will have on rainfall patterns, and consequently the impact that climate change will have on the ability of RWH systems to provide adequate quantities of water over a year-long period. Much less research has been conducted on whether RWH projects can support communities in adapting to new climate unpredictability and uncertainty around water availability.

Kahinda, Taigbenua & Borotob (2010) believe that rainwater harvesting with on-site storage can enable communities in sub-Saharan Africa to be more resilient to increased hydrological uncertainty by providing a 'buffer' of water supply and storage in times of unexpected drought. It can also reduce the impacts of localised flooding by channelling water into storage tanks. In this way, RWH is seen as a mechanism to reduce climate risk for water insecure communities (Boelee *et al.*, 2013).

Within this literature review, only five papers have been found that refer to RWH in the context of water security (Bitterman *et al.*, 2016; Kahinda, Taigbenua & Borotob, 2010; Kisakye & Van der Bruggen, 2018; Musayev, Burgess & Mellor, 2018; Staddon *et al.* 2018). The few studies that do refer to rainwater harvesting in this context, fail to describe the multiple characteristics associated with water security.

Musayev, Burgess & Mellor (2018) do not define water security at all but find that domestic rainwater harvesting has the potential to improve household water security under several future climate scenarios. In the case of their research, the term 'water security' refers to ensuring current and future access to water. In order to be effective at mitigating against drought, they find that tank size must be suitably large to store enough water to meet predicted demand over the dry season. There are challenges with the practicalities of ensuring a large enough tank size as cost and availability of space are limiting factors.

Kisakye & Van der Bruggen (2018) also assess the effects of climate change on water security, but critically, reduce the definition of water security down to '*the number of days a tank of particular size is empty as a ratio of the total number of days in a given period'*. Kahinda, Taigbenua & Borotob (2010, p.744) assess domestic rainwater harvesting in South Africa as a climate change adaptation strategy but define water security simply as the '*percentage of household demand that is satisfied'.*

Bitterman *et al.* (2016) develop a model of water security from rainwater harvesting for agricultural use in the Tamil Nadu region of India, elaborating further by defining water security as *'the sufficient availability and equitable access to water as an input to agricultural production and associated human wellbeing'*. This definition integrates the availability and accessibility components of water security but does not take a more holistic view of the term, with no mention of the role of technology management, governance or human rights in contributing to water security. In most of these pivotal papers that unite RWH and water security there is no exploration of the meaning of water security (as described by leading water institutions and academics).

The exception is a publication from Staddon et al. (2018) that describes a ‘hydro-social’ model of defining water security in relation to RWH adoption trends in Uganda. In emphasizing the cultural, social and political relations behind securing water, Staddon *et al.* (2018, p.1119) find that

> *‘achieving water security is a dynamic process, bridging the gap between socio-political relations on the one hand and the acquisition of physical water on the other’.*

Staddon et al. (2018) deliver discussion on the various concepts that relate to water security in their research, and adopt the ‘relational’ approach to water security, which was first presented by Jepson *et al.* (2017). This approach recognises the wider interactions that take place between people and water (as opposed to solely referring to physically securing water). In this paper, while water security concepts are described in detail, they are not used as a tool to guide the assessment of the drivers, barriers and outcomes of RWH adoption. As a result, the relationship between domestic RWH and water security has not been fully explored.

3.6.1 Rainwater Harvesting and Reliability

One of the biggest drawbacks of RWH is that it depends on consistent rainfall to provide adequate year-round water supply. This drawback can be overcome if significant on-site water storage is available, but this storage comes at a high capital cost. Uganda has bi-annual rainy seasons, which allow for two periods of water collection throughout the year, but, typically, the months of June to August experience very little rainfall (World Bank, 2020).

Several studies that look directly at the reliability of RWH use daily water balance models to estimate the amount of water on any given day in a rainwater harvesting tank (Bitterman *et al.*, 2016; Campisano *et al.*, 2013; Kisakye & Van der Bruggen, 2018; Imteaz *et al.*, 2012; Liu *et al.*, 2015; Liuzzo, Notaro & Freni, 2016). Reliability is typically defined as numbers of days in a year where a RWH system can meet demand and depends on rainfall levels and the management of water conservation practices (Haque, Rahman & Samali 2016). Climate change is impacting the distribution of rainfall in sub-Saharan Africa, prolonging periods of drought and adding to uncertainty over rainfall collection.

Many researchers have modelled various climate scenarios using General Circulation Models (GCMs) and used a variety of roof size and tank size combinations to assess RWH system reliability (Haque, Rahman & Samali, 2016; Musayev, Burgess & Mellor, 2018; Kisakye & Van der Bruggen, 2018; Almazroui *et al.*, 2017).

Kisakye & Van der Bruggen (2018) model the future effects of a changing climate on the availability of water in a RWH tank and explain that rainwater availability is greatly influenced by roof and tank size, household demand and weather and climate variability. They find that a common issue in Uganda is that tank sizes are not designed to meet catchment size and so tanks often overflow, wasting water. Conversely, when demand is not taken into account before RWH system installation, they find that tanks are often empty on too many consecutive days due to prolonged dry spells and high demand. While research to date has focused on understanding the impact of climate on RWH reliability, further research should look at whether water management and conservation practices can improve RWH reliability.

3.6.2 Sociotechnical Constraints on Rainwater Harvesting

To better understand why uptake of RWH is below targets set by the United Nations, more information on the factors that constrain uptake is needed. Campisano *et al.* (2017) conduct a global assessment of rainwater harvesting systems with a focus on the sociotechnical factors that lead to the successful implementation and uptake of the technology. They find that despite significant technical innovations in recent years, innovation in service delivery has been limited. Across the world, rainwater harvesting systems are installed with the sole aim of providing and preserving water. They call for other potential benefits of RWH, such as the impacts of on-site water storage on human health, gender equality and children's education, to be explored. Campisano *et al.* (2017) state that further research should focus on how institutional and socio-political support can improve the level of community acceptance of RWH.

According to Campisano *et al.* (2017), constraints on the use of RWH in developing countries such as local regulation and costs of implementation and maintenance play a key role in system penetration rates and the uptake of the technology. They conclude that there has been substantial research globally on the technical aspects required to ensure well-functioning RWH systems that provide good quality non-potable water. Increased effort is needed to understand how better system maintenance can be encouraged, and to understand the impact that improved maintenance can have on the potential for RWH systems to provide better quality water. Interdisciplinary research including analysis on how to improve system efficacy and community participation is required generally in the field of RWH (Campisano *et al.*, 2017).

Lee *et al.* (2016) assess the environmental, political, economic, social and technical challenges of RWH in Malaysia. This type of assessment is much less common than those that focus solely on the technical challenges but can uncover the conditions under which RWH is an appropriate water-provisioning technique. They find that there are several challenges associated with the uptake of RWH in Malaysia. These include new climate unpredictability rendering RWH inappropriate for much of the year when there is no rain, and a lack of policies to support the installation of RWH. High capital costs required to install RWH systems and poor public perception of the efficacy of RWH both act as a deterrent to users (Lee *et al.*, 2016).

Similar studies have been carried out in countries in sub-Saharan Africa such as that by Dismas, Mulungu & Mtalo (2018) which assesses opportunities for the application of RWH technologies, communities' willingness to adopt RWH technologies and challenges for the installation and maintenance of RWH systems. They find that significant barriers to the adoption of RWH include a lack of knowledge on maintenance and high initial investment costs. These socio-technical constraints need to be taken into consideration when assessing whether RWH is an appropriate approach to improve water security, or whether alternative approaches are preferred by users, and so are more likely to be well-maintained, understood and accepted in the long-term.

Assayed *et al.* (2013) assess community-based initiatives for water demand in Jordan and find that RWH is most appropriate as a water management technique for communities that do not have access to public water supply. In contrast, Haque, Rahman & Samali (2016) believe that RWH should be coupled with other water-provisioning practices, particularly in countries where dry seasons can extend to six-months. Pandey, Gupta & Anderson (2003) and Kahinda, Taigbenua & Borotob (2010) agree that as a supplementary water supply, RWH offers an important mechanism to adapt to water insecurity because it provides flexibility in water access by making water available when needed. Referring back to the urban/rural divide, it is often urban users that choose to supplement mains water with RWH, whereas rural users in LDCs often adopt RWH as a primary water source in the absence of centralised supply.

RWH is often referred to as a 'sociotechnical' intervention, as its sustained use depends on the right combination of physical and social conditions (Staddon *et al.* 2018). Successful operation requires the infrastructure to be correctly installed and for owners to undertake regular inspection and maintenance. Calls for further research into the sociotechnical drivers, barriers and outcomes can be met by using the multi-faceted concepts associated with water security to support the identification of these factors.

3.7 Chapter Summary and Research Gaps

In this chapter, existing knowledge and discussions on the topic of water security have been presented. There is broad agreement that framings of water security go beyond simple framings of water supply and demand. 'Water security' has been adopted by leading water institutions and scholars to describe the complex relationship between humans, water and the environment.

Despite the high number of publications focused on defining water security, **there is a lack of knowledge on how best to operationalize the core concepts associated with water security**. Suggestions for contributions to fill this gap include applying new assessments of water security to specific case studies (communities, cities, regions) and understanding how water services can contribute to water security on various scales.

There is an absence of existing frameworks designed for the assessment of how decentralised water services in low-resource settings meet water security goals. **Several authors call for more research to understand how to contribute to water security through small-scale, decentralized community-scale water services.** In answering research sub-question (2), this research project contributes to filling this research gap.

Research has shown that RWH has the potential to contribute to better water security, but there are significant barriers to adoption that vary depending on geophysical and socioeconomic context. Identifying how to overcome these barriers may provide a better understanding of how to improve uptake of RWH in sub-Saharan Africa. The main research question of this thesis aims to identify the specific drivers, barriers and outcomes of RWH use in Ugandan communities. The literature review has highlighted a need for further research into what institutional and socio-political support can improve uptake of RWH.

To answer research sub-question (2) empirical fieldwork that both represents real-world user relationships with RWH systems and improves knowledge of how to apply the multiple dimensions associated with water security, is needed. Water security frameworks can provide structure to assess the sociotechnical drivers, barriers and outcomes of RWH access, but this literature review has highlighted that very few scholars have approached the RWH-water security relationship in this way. Instead, the focus has been on assessing whether RWH can physically provide enough water for users. As a result, there is a lack of knowledge of how RWH can meet the range of water security goals that are associated with human wellbeing and socioeconomic development. New contributions to knowledge should focus on identifying the socioeconomic, technical and environmental outcomes of RWH access.

In this literature review, **multiple calls for new contributions to focus on water security at a community scale** have been highlighted**.** Water security has been assessed by scholars at community, local, city-wide, national and transboundary scales. Through this review, no studies were found that compared and contrasted the water security of rural and urban populations within a given country. Answering research sub-question (3) and **comparing interventions for water security between rural and urban populations can provide insight into how localised environmental, institutional and socioeconomic conditions influence water security for the two user groups.**

The critical research gaps are in operationalising the concepts associated with water security and assessing RWH through the lens of water security, considering economic welfare, equitable access to water, climate risk and the long-term, sustainable use of RWH systems and more. In order to carry out this type of assessment, a conceptual framework to provide answers to research sub-question (1) is first needed. This will help to identify and clarify how water security is defined by core stakeholders invested in the provision of community water services in Uganda. The following chapter presents the design and development of this framework.

4 WATER SECURITY FRAMEWORK

The water security framework presented in this chapter provides a tool for the assessment of RWH use in Uganda. Building upon findings from the literature review, the aim of the framework development is to provide answers to research sub-question (1) '*How can the concepts associated with water security be framed to assess the sociotechnical outcomes of rainwater harvesting use in Uganda?'* Referring back to the research gaps identified in Chapter 3, the framework adds to knowledge on how to assess and operationalise the core concepts associated with water security.

Within the water security framework are ten goals for community water security and thirty-two metrics that can be used to assess whether water services meet these goals. The methodology used to develop the framework, along with the criteria for selecting the goals and metrics, are discussed. A detailed description of each of the goals is presented, supported by findings from interviews with water practitioners and stakeholders involved in the delivery of water services in Uganda.

4.1 Development of Water Security Framework

The literature review highlighted calls for further research to bridge the gap between the conceptualisation of water security and the assessment of real-world techniques to improve water security. In the absence of existing frameworks designed for the assessment of the contribution of decentralised water services to community water security in low-resource settings, a new framework was developed. Semi-structured interviews were carried out with stakeholders invested in the provision of community water services in LDCs and in Uganda in particular. The framework was designed for use in Uganda, so initially stakeholders with specific experience in Uganda were sought. In some cases, interviewees drew on their experience working more broadly in low-resource settings.

Stakeholders included WASH practitioners from global NGOs, water experts from think tanks and government departments, plumbers, water specialists and water operators from the case study region. The intention was to engage both stakeholders with a pre-existing knowledge of water services within the case study context and experts in the field of decentralised water provision in Uganda. By developing the framework based on the perspectives of water practitioners, information was gathered on how water security concepts are currently being put into practice, and decisions were made about which concepts should be prioritised for assessing community scale water services.

As it is water practitioners, and not researchers, who are involved in the day-to-day implementation and management of water services, theirs was viewed as a critical voice to contribute to understanding which water security concepts should be prioritised when assessing the outcomes of RWH interventions.

4.1.1 Stakeholder Interviews

Thirty-two semi-structured interviews were carried out between October 2018 and July 2019. Interviewees were selected based on their organisation's role in the water and sanitation sector, interviewee expertise in WASH project implementation in Uganda, and their willingness to participate. As the intention of the interviews was to develop concepts associated with water security, interviewees who were likely to have prior knowledge of the term were contacted (specifically WASH practitioners, or interviewees in charge of on-the-ground operations).

Interviews were conducted face-to-face, via telephone, or via video conference. Initially, ten interviews took place in person during the scoping study in Uganda. In addition, 48 organisations from the water and sanitation, global development and humanitarian sectors were contacted for interview. These organisations were selected from academic conferences attended and from grey literature (e.g., during the literature review, the Overseas Development Institute was identified as a significant contributor to water security dialogue, and so the authors of relevant ODI publications were contacted for interview). Interviewees were provided with information about the research project and provided with a participant information sheet and consent form and informed that their anonymity would be preserved. All interviews were recorded with a digital voice recorder and later transcribed.

Of the forty-eight organisations contacted via email with a request for interview, twenty-four stakeholders responded agreeing to be interviewed. In total twenty-two interviews took place with representatives from the organisations contacted by email. Two respondents did not feel they had adequate knowledge to contribute to the study. Interviewee roles, organisations and interviewee codes are presented in Table 9. Interview codes in the form of 'ST#' are used in this chapter to indicate reference to interviewees' comments and to protect interviewees' anonymity. There was no arbitrary number of interviews required; instead, data saturation was sought. Charmaz (2006) explains that saturation occurs when gathering fresh data no longer reveals new insights or properties associated with the phenomenon that is being studied.

Role	**Organisation**	**Interviewee Code**
WASH Advisor	Tearfund	ST01
Rural Sociologist and Gender Expert	International Water Management Institute (IWMI)	ST02
Chief of WASH	UNICEF	ST03
WASH analyst	Department for International Development (DfID)	ST04
Founder/WASH specialist	Centre for Humanitarian Change	ST05
Monitoring and Evaluation Advisor	Save the Children	ST06
WASH Advisor	Independent Consultant	ST07
Sustainability Officer	Life Water	ST08
WASH Coordinator	Impact Water	ST09
Research Fellow	Overseas Development Institute (ODI)	ST10
WASH Engineering Advisor	Concern Worldwide	ST11
WASH Advisor	Centre for Affordable Water & Sanitation Technology (CAWST)	ST12

WASH Programme Advisor	WaterAid	ST13
Programme Coordinator	UNHCR	ST14
Programme Coordinator	The Johanniter	ST15
Programme Coordinator	Just a Drop	ST16
WASH Programme Manager	SEED International	ST17
Operations Manager	eWaterPay	ST18
WASH Programme Specialist	Oxfam	ST19
WASH Advisor	World Health Organisation (WHO)	ST20
WASH Coordinator	WaterAid Uganda	ST21
Emergency Water & Sanitation Engineer	Médecins Sans Frontières (MSF)	ST22
Water Resources Manager	Uganda Ministry of Water and Environment	ST23
Country Coordinator	Impact Water Uganda	ST24
Treatment plant manager	National Water and Sewerage Corporation	ST25
Head of WASH	KDWSP	ST26
Coordinator	Mbarara Plumbers' Association	ST27
CEO	Afrinspire	ST28
Coordinator	Mbarara Development Studies Centre	ST29
Group Leader	Mbarara Women's Group Leader	ST30
Gender Studies Academic	Mbarara University of Science and Technology	ST31
University Tech Hub Coordinator	Mbarara University of Science and Technology	ST32

Table 9 - Interviewee role, organisation and interviewee code

A semi-structured interview approach, where the interviewer has a series of questions in a general form known as an interview guide, was adopted for the stakeholder interviews (Bryman, 2008). This approach was deemed appropriate as it allowed for both flexibility and a wide range of topics to be covered. The approach encourages interviews to be tailored to individual participants based on their expertise. Not all questions were covered in every interview, and there were some characteristics of water security that were discussed in greater detail by certain interviewees stemming from their experiences. For example, those interviewees from organisations that focused on funding for water provision spent significant time discussing financing mechanisms for water services. It is for this reason that a wider range of stakeholders associated with water services in low-resource settings was sought – so that points of view from multiple perspectives were taken into account.

The interviews contained questions on the following four main themes:

I. Water security meaning and metrics
II. Current methods of assessment of water-provisioning and WASH projects
III. Decentralised water services (including RWH)
IV. The role of water security in water project assessment and implementation.

The complete stakeholder interview guide can be found in Appendix I. Saturation was thought to have been achieved through the interviews when no new characteristics of water security were identified, and when there were recurrent descriptions of the same water security goals. This is not to say that all interviewees identified all of the water security goals presented in the framework, but saturation occurred when no new goals were identified by interviewees and no new concepts discussed.

4.1.2 Limitations of Interview Method

The stakeholder interviews lasted between 30 and 50 minutes. Certain stakeholders were more forthcoming as they felt they had a longer window with which to discuss the interview topics in detail, and so the input of some stakeholders over others was greater.

Selection of interviewees was dependent on their willingness to participate. For example, an interview had been arranged with a senior decision-maker at the Ministry of Health in Uganda but was cancelled last minute and so the voice of a significant actor was not represented. Nonetheless, the range of stakeholders involved in the interview series covered notable and significant actors from the WASH and global development sectors. It must be noted that there were time and logistical limitations on the number of interviews carried out face-to-face in Uganda and ten was the maximum that could be achieved in the short timeframe of the scoping study visit. This may have meant that stakeholders with community knowledge were underrepresented in the design of the framework.

A notable drawback of the semi-structured interview approach was that not all interviewees were asked exactly the same questions. This can create difficulties in identifying common themes and guaranteeing a consistent research process. However, through the transcription and the rigorous coding process, commonalities in responses and dominant themes were readily identified.

The researcher's interpretation further limits the findings. Misinterpretation of findings may have impacted the conclusions which were drawn from the stakeholder interviews. In order to mitigate against misinterpretation, a preliminary framework was shared and reviewed with five interviewees during follow-up interviews. Securing these follow-up interviews was limited by interviewees' availability. Ten interviewees were contacted for follow-up interviews but only five agreed to participate. These interviewees were selected based on their previous knowledge and experience of water security concepts. The interviewees that participated in the repeat interviews are shown in Table 10.

Role	Organisation	Interviewee Code
WASH Advisor	Tearfund	ST01a
Chief of WASH	UNICEF	ST03b
Monitoring and Evaluation Advisor	Save the Children	ST06c
Research Fellow	Overseas Development Institute	ST10d
WASH Engineering Advisor	Concern Worldwide	ST11e

Table 10 - Repeat interviewee role, organisation and interviewee code

Interviewees were asked to assess how well the framework represented their understanding of water security. They were asked to what extent they agreed with the goals and metrics that had been selected (on a scale of 1-5, where 1= not at all, 2= poorly, 3=to a degree, 4=well and 5= very well), what was missing from the framework, whether they found the framework clear and how well the framework represented what they deemed to be the important components of community water security in Uganda. Although the framework was designed specifically for implementation in Uganda, interviewees were asked about the relevance of the framework in LDCs in general, as for two interviewees significant time had elapsed since they had worked in Uganda.

In response to the question ‘to what extent do you agree that the goals in the framework represent community water security?’, three participants responded with 4 (well) and two participants responded with 5 (very well). As a result of the follow-up interviews, certain updates were then made to the framework based on recommendations by the interviewees. One such example is with a goal initially labelled ‘acceptable water quality’. During the follow-up interviews, three interviewees stated that this labelling should include reference to the relationship between water quality and health. On reviewing both the coded segments referring to ‘water quality’ and ‘health’, this goal was updated to ‘acceptable water quality for good health’.

4.1.3 Interview Data Analysis

Interview data was transcribed and then coded using the computer software programme Nvivo 12.6.0 (QSR International). Coding is the practice of assigning a label to a section of data using a word or short phrase (Given, 2008). Codes served as devices to label, separate, compile and organise data (Charmaz, 2006). The process of coding was iterative where the researcher moved back and forth between the various stages of coding and the analysis of data. Throughout the interviews, memo-taking was carried out to assist in the coding process (Bryman, 2008).

The first cycle of coding involved line-by-line coding of the interview transcripts. This resulted in 336 coded segments. This round of coding involved selecting segments of statements and categorising them into groups. For example, the statements: ‘the burden of water collection falls mainly on women’ and ‘men maintain water technology’ were both categorised under the heading ‘gender roles’. The codes developed for this round along with a description of each code are presented in Table 11.

Code	Description
Affordability	Mentions of pricing of different water services and comparisons between centralised and decentralised costs
Framings of WS	Mentions of water security including any description of well-known definitions
Climate change	Mentions of the impact of climate change on poverty, water services and populations
Climate variability	Mentions of long-standing and new climate patterns, and changes between the two
Climate impacts	Points on the impact of weather, climate, rainfall, population displacement etc.
Cost and financing	Mentions of payment mechanisms, subsidising water services, financial support for water services
Crop growth	Mentions of crop growth and the relationship between climate and crops
Environmental risk	References to risks to the environment and measures taken to protect the environment
Agriculture	References to agricultural (pastoral and arable) activities, communities and income-generating activities
Equitable access	Mentions of different user groups that need access to water
Gender roles	References to gender roles and gender disparity in water management, collection and access
Health impacts	Reference to disease burden and health challenges associated with water access
Floods and droughts	Reference to the impact of flooding and droughts on water access and livelihoods
Availability of water	Mentions of year-round access to water and different water sources and services
Holistic approach to human-water relationship	Descriptions of approaches to human-water relationships that consider more than just the materiality of water
Household water storage	Description of on-site water storage including challenges and impacts
Livelihoods	Mentions of livelihoods, income-generating activities and connections between water supply and livelihoods
Institutional support	Discussion on institutional support at any level (global, national, local). Mention of specific institutions and mechanisms that support water security
Extreme weather	Reference to weather events such as typhoons, hurricanes, flooding rainfall
Uncertainty	References to uncertainty around weather patterns, securing water for the future and long-term water access
Income-generating activities	Descriptions of specific activities that generate income including agricultural and entrepreneurial activities

Water quality	Reference to the quality of water from decentralised and centralised water services and measurement techniques to assess water quality
Water quantity	Reference to 'enough water' and amount of water required and received by different populations
Long-term sustainability	Descriptions of the upkeep of water services and the sustainability of services in terms of the length of time they last
Sustainable development goals	Reference to any of the sustainable development goals and specific reference to SDG 6
Management of water services	Descriptions of roles, responsibilities and actors who are involved in the management of water services at any scale (local, regional, national)
Institutional support	Description of actors and institutions that support water services. Explanations of how institutions provide support and where further support is needed
Financing mechanisms	Reference to how populations pay for water services, barriers to payment and support structures to ensure payment can be made
Origins of WS meaning	Definitions and descriptions of water security, where it originated from and how it has evolved
Poverty-water relationship	Reference to any relationship between LDCs, low-income populations, poverty and water access
Scales for assessment	Any reference to appropriate scales for assessing water security and benefits and drawbacks of each scale
Self-supply and management	Mentions of self-supply and moving up the water technology ladder. References to ownership of water services
Framing of water access	References to different framings of water access including mentions of specific water services such as boreholes
Integrated water resources management	References to IWRM in reference and in contrast to water security
Resilience of water services	Specific mentions of resilience of water services to climate shocks, unexpected events, interruptions and extreme weathers
Community resilience	Mentions of the resilience of the community to any event, experience or situation
Water access	All references to accessing water, proximity of water, and any barriers to water access
Conflict over water supply	Mentions of causes of conflict and types of conflict that may arise over water access at any scale
Metrics	Any mention of metrics that are used to assess the outcomes of water supply projects

Table 11 - Codes developed during the initial round of coding of the stakeholder interviews

The next round of thematic coding aimed to further group and reduce the number of codes. This round involved exploring the relationship between the codes and then grouping the codes into wider common themes. For example, ‘gender roles’, ‘role of children in water collection’, ‘remote users’ and ‘lowest income users’ were all grouped into a code called ‘water access for vulnerable groups’. At this point it was clear that some of the coded statements would not contribute to the water security framework, but instead would provide context and greater understanding of water security, for example, coded segments under ‘definitions of water security’ and ‘scales for assessment’.

Finally, the water security goals were selected from the codes. As the framework was designed to be used specifically for the identification of sociotechnical outcomes, one water security characteristic that was prominent in the literature but was not frequently mentioned by interviewees was ‘protection of ecosystems’. This is likely because the questions that were asked during the interviews focused on social, physical, technical and economic characteristics of water security. It may also be that the omission of ‘protection of ecosystems’ is down to the scale at which the framework is designed to be applied. The literature review highlighted that reference to ecosystems tends to occur within the context of larger scale studies rather than community studies.

Criteria to select the goals for the framework were:

1. Their applicability to decentralised water services in a community context and on a community scale. For example, references to international transboundary conflict were not included in the coded segments that contributed to the final community water security framework.
2. The frequency with which they were mentioned by stakeholders. Concepts that had less than ten coded segments attached to them were not considered. This was to ensure both that detailed descriptions of concepts could be provided and that they were deemed significant by stakeholders for community water security.
3. Applicability to decentralised water services in low-resource settings. All of the stakeholders interviewed discussed WASH services in low-resource settings as this was a criterion for selection of interviewees. However, where references were made to water services in OECD countries, these references were not included in the coded segments that contributed to the final goals for the framework.

Following on from the identification of the goals, metrics were developed through findings from the stakeholder interviews. During the interviews, questions were asked about current metrics and methods of assessment of WASH projects (See Appendix I for details). In the initial round of coding, where 336 coded segments were identified, any segment that referred to the measurement of water security or the outcomes of water supply services were assigned the code ‘metric’, as can be seen in the final row of Table 11. Metrics were selected based on the following criteria:

1. **Accessibility -** The ease with which the metric could be assessed in the field. As the framework is designed for practitioner use in the field, metrics for which data could be easily collected using the qualitative and quantitative methods described in Chapter 2, were prioritised.
2. **Relevance –** Metrics that specifically helped to identify whether water services were contributing to the water security goals presented in the framework were prioritised. For example, interviewees would discuss current metrics they use to assess the success of water delivery projects, but unless these metrics were used to assess a specific goal that had been identified for the framework, they were discounted.

This selection process resulted in the development of the thirty-two metrics presented in the framework.

4.2 Water Security Goals

The identification of the water security goals helps to make up a new working definition of water security adopted for this research project. This definition is presented in Figure 8.

Figure 8 - Framing of decentralised water services that contribute to community water security in low-resource settings

‘Water services that contribute to community water security provide sufficient water of acceptable quality for good health, which is affordable and available year-round. They sustain livelihoods and can be equitably accessed across all user-groups. These water services should minimise the risk of local conflict and boost community cohesion and climate resilience. The management of these services should be supported by local and national institutions so they can be reliably sustained over the long-term’.

In order to demonstrate the rationale behind this definition, exemplary quotations are presented below to justify, explain and provide detail and context for the selection of the goals in the framework. Complete quotations are presented where they provide illustration of a concept, and interview codes are provided when either more than one interviewee referenced a similar point, or a description of themes provided better illustration than a direct quotation.

The wording associated with **acceptable quality for good health** is important. ‘Acceptable to whom?’ was a question that several interviewees asked (ST02, ST03, ST13, ST26). Users’ perception of water quality was deemed to be as important as physiochemical and microbiological test results. The interviewee representing the WHO provided the example of chlorinated water. Chlorination is a cheap and effective method of water purification, but it can create chemical-tasting water. End-users often choose to consume turbid water rather than chlorinated water in order to avoid strong chemical taste. In this case, the chlorinated water would be likely to meet WHO standards, whereas the turbid water would not, but if end-users do not want to drink it, then ‘acceptability’ is not met (ST20).

There is a strong relationship between water quality and health, but on a small scale, without adequate equipment, measuring the causal relationship between water quality is challenging (ST14, ST20). Good quality water is not a goal unto itself. Instead, the value in acceptable water quality lies in the reduction in waterborne disease within a community

(ST01a, ST06c). Hence, the wording of this characteristic includes reference to quality, health and acceptability.

Affordability of treatment was viewed as a significant factor that influenced the adoption of water treatment technologies; however, when water quality was discussed in relation to the other two 'pillars' (ST13) of water security (availability and quantity) it was deemed to be a lesser priority than proximity and quantity of water:

> *'I think quality is valued when quantity is adequate, and I think people do understand very well the links between poor water quality and disease. I think where people can get affordable treatment methods, they will use them, but where they have to pay a lot of money for them, they tend not to' (ST09).*

Year-round availability was frequently referenced and referred to both the proximity of water sources and availability throughout seasonal variations in rainfall, groundwater and surface water supply (ST04, ST05, ST07, ST09, ST11, ST17, ST29). For good water security, proximity of water was viewed as essential:

> *'Reducing the distance between users and [water] sources is essential for populations to become water secure. Often women will collect water in the middle of the night because that's when there are fewer queues and then there are problems with their safety as they travel. We know that a lack of close access to water is a huge driver of so many of the problems that we see in society in developing countries. It's to do with health, to do with education, and income opportunities' (ST08).*

In the context of year-round availability of water in sub-Saharan Africa (SSA), extreme weather patterns were viewed as a barrier to the availability of water (ST02, ST04, ST26, ST30):

> *'If intense rainfall events happen at the wrong time, they can massively undermine agriculture. At the other extreme, in arid and semi-arid lands, a lot of the water supply is still surface water. The minute you get high*

temperatures, you lose those water resources much faster and much earlier in the dry season. Plus, of course, the burden of fetching water when the temperatures are risen to the high forties, which they were back in January, is pretty intense' (ST02).

Out of the three physical descriptors (quantity, quality, availability) of water security, **sufficient quantity** was deemed to be the most essential component of a water secure community:

'The issue of enough water is the key determinant of water security. Once you have enough water, you can carry out essential water-associated activities such as hand washing. Enough water for hand washing leads to better productivity and more disposable income' (ST24).

'Enough' water is measured by the WHO standards of 20 litres/person per day and by whether supply of water can meet demand (WHO, 2012). 20 litres/person/day is deemed adequate for basic hygiene needs and food washing. However, it is still far below the optimal quantity for domestic use, which is 100 litres/person/day (WHO, 2012).

It was emphasised that water services needed to be both **climate resilient**, and also be delivered in a way that encouraged human resilience to extreme weather events and unpredictability. This was cited as a significant challenge (ST16, ST22, ST24). While a number of interviewees (ST03, ST06) questioned whether climate change was a real driver of water security challenges, or whether, in fact, long-term interannual variations in weather patterns had always been a challenge for the management of water, several interviewees felt confident that climate change was creating uncertainty around availability of water resources:

'If every year you could predict which months were going to be dry, when the rain was going to come back, and therefore exactly where the ground table was throughout the year, then maybe education around storage and restricting use or whatever, would get you somewhere. Now though, things

are so unpredictable that no amount of education can prepare you for zero rainfall' (ST07).

Adaptation to the impacts of a changing climate on water access was deemed essential to protect livelihoods, but interviewees had varying views on what adaptation entails. Some interviewees saw adaptation as retrofitting existing infrastructure: '*we've raised the elevation of certain handpumps we installed 5-10 years ago in order to keep them away from flooding*' (ST19), while others saw socioeconomic changes such as urbanisation as a natural form of building human resilience to the unpredictability of weather patterns:

'A big part of shifting from being a poor agrarian community to being a developing middle-income community is about manufacturing, about shifting low-skilled agricultural labour into relatively low-skilled light manufacturing or textiles production' (ST07).

Affordability of decentralised water services was referred to as critical for sustained and equitable access. Stakeholders in Uganda cited high costs associated with centralised water as one of the biggest barriers to household water access, explaining that despite the presence of water infrastructure, many urban households chose not to connect to the water grid because they could not afford the monthly bills (ST25, ST27, ST30). Equally, the high capital costs associated with private boreholes and rainwater harvesting were seen as a deterrent to the adoption of decentralised water supply (ST26, ST29, ST30). Affordability of water services was referred to as integral to ensuring water access in Uganda:

'In most of the cases we work with, the reason communities can't access water is economic and not due to physical access issues' (ST23).

Links between funding and whether decentralised water services **can be sustained** over the long-term were made, with one interviewee stating that:

'Funding is the biggest driver of the sustainable upkeep of [water] services' (ST04).

Most interviewees used the term 'sustainability' to refer to long-term use of water services, which was cited as a desirable goal by multiple stakeholders (ST09, ST12, ST16, ST17, ST19, ST20). One interviewee believed that the sustainable upkeep of services was the biggest challenge facing water projects in sub-Saharan Africa (ST10d). Whether services can be sustained in the long-term was seen to be decided by both the quality of the projects delivered and the capacity of the community to maintain those projects:

> *'There is a focus on ensuring the hardware is up to scratch, but we need to shift that focus to now ensure water [provisioning] systems can be sustained in the long-term. This is done by ensuring water committees have the capacity and support to carry out maintenance'(ST01).*

Ultimately, the water sector is working towards providing all populations with centralised water services, with decentralised services viewed as an option to 'plug the gap' until this is possible:

> *'We need to be designing decentralised [water] infrastructure that can be sustained for 100 years, because hopefully in 100 years' time, the governments should be supplying the water anyway' (ST18).*

Other stakeholders agreed that decentralised water services should be designed with a lifespan of 100 years. However, in reality, this is rarely achieved (ST07, ST17).

Water services that **encourage equitable access** are specifically designed or placed with vulnerable groups in mind. There were contrasting opinions on how this could be achieved, with stakeholders belonging to two camps – those that believed community services encouraged more equitable access, and those that believed that household services ensured specific users were provided with water. Vulnerable groups identified included women, children and the poorest users (ST22, ST26). At a household level, women were viewed as responsible for water management. However, this did not translate to the community level:

'In our studies, women are very empowered at the household level to manage water in the house, but they're very unempowered to manage water in the community as a whole' (ST30).

In response to this, one approach that has been adopted by stakeholders is to engage women in community water committees (ST19). However, another interviewee cautioned that to improve quality of life for women, the focus should be on ensuring proximity of water services, rather than on providing women with greater responsibility within the community:

'Some of our studies have indicated that where water security is very poor and fetching water is a huge part of their day, it does not benefit women to give them additional responsibilities. Adding to that workload can be counterproductive in reducing their burden' (ST12).

This contrast in opinions highlights how equitable access to water services is a contested concept. Questions must be asked about which user groups should be prioritised and how best to engage these groups in the delivery of water services so that a balance can be found between ensuring a sense of ownership and encouraging access for groups that cannot afford household services (ST13). Another drawback of community water services is they can often become overrun by illegal operators who begin to charge users for water, marginalising the poorest user groups further (ST05). The risks of illegal operators can be mitigated by increasing support from institutions in the management of decentralised community water services (ST17).

Effective management with support from institutions was highlighted as a critical characteristic for community water security. The role of institutions in the sustainability and effective management of water services was highlighted by several interviewees (ST04, ST10, ST23). Interviewees' opinions on whether decentralised services should be managed by end users or institutions differed, but engagement with national governments was seen as essential for effectively managing water services:

> *'There has to be some kind of overarching structure provided by governments to support decentralised water services. Day-to-day management may be done by NGOs and community members, but there has to be some degree of support and backstop from the public sector'(ST03).*

Risk of conflict over water resources is more traditionally associated with transboundary scales. However, **mitigating risk of conflict** and encouraging community cohesion was identified as a top priority for two stakeholders (ST19, ST22).

When resources are limited, the provision of decentralised water services can create conflict (ST15). Conflict over management of services is common:

> *'We must be really careful not to enter a community and create conflict by exacerbating local tensions over power. In some cases, community services just aren't appropriate, so we provide household solutions, but even these can cause jealousy and resentments' (ST16).*

Local 'water gangs' can hijack water services, giving priority to certain user groups and disenfranchising others (ST19). In attempts to overcome this, water committees are set up to manage water services, but it is often members of these committees that are underhandedly controlling and charging for water services (ST22). Embedding a sense of community ownership of services was cited as a strategy to mitigate conflict within communities (ST01). Conflict mitigation was cited by multiple stakeholders as a goal of water security, where, in contrast, through the literature review, few formal definitions of water security referring to conflict mitigation were found. This may reflect the impact of assessing water security on a community scale, where sensitivities and power struggles over water access are more visible. It may also be a reflection of the difference in priorities between academics and practitioners, where practitioners are more sensitised to the impacts of their interventions on community dynamics.

Finally, the role of water in **supporting livelihoods** has been well documented as a feature of water security. In some parts of Uganda, women spend as much as three hours a day fetching water (ST31), limiting the amount of time they can dedicate to other tasks including income-generating activities:

> *'We have to cut down the amount of time women are spending on household water activities. When you do that, you free up their ability to work, whether in the agricultural sector or any other'(ST30).*

Reducing the time spent fetching water isn't the only economic benefit of improved water access. Water is the bedrock of agricultural activities, which is how the majority of rural residents in Uganda generate income (ST29). Ensuring there is enough water for agriculture is essential for economic growth in south-west Uganda (ST21). In order to support livelihoods, there must be enough water for a variety of economic activities:

> *'An absence of water can stop the local economy in its tracks. I've seen construction projects halted half-way because there's not enough water to make the concrete. The projects are just left in that way, sometimes for years. Knowing how much water is required for which activities and ensuring that availability is critical for the local economy'(ST26).*

In addition, the water sector in itself provides local employment through technology maintenance and water vending roles. Where employees can be locally employed the subsequent socioeconomic benefits remain with the communities.

4.3 Water Security Metrics

The framework is designed to link theoretical concepts to techniques to assess these concepts. In the central ring of the framework are the metrics used to indicate whether each goal is being met. In Table 12, water security goals, metrics and the methods of data collection during the case study assessments are presented.

Water Security Goal	Metric	Method of Data Collection
1. Water of acceptable quality	User perception	End-user interviews
	Bacteriological tests	Remote water quality testing
	Prevalence of waterborne disease	End-user interviews
	Physiochemical tests	Remote water quality testing
2. Water available year-round	Distance to source	End-user interviews, focus group discussions, key informant interviews
	Time taken to access water	End-user interviews, focus group discussions, key informant interviews
	Impact of seasonal variability	End-user interviews, focus group discussions, key informant interviews, water balance models
3. Sufficient quantity of water	Whether supply can meet demand	End-user interviews, water balance models, site assessments
	Number of litres/day supplied	
4. Water services are resilient to local climate impacts	Mitigates unpredictability of rainfall	End-user interviews, water balance models
	Buffer of water supply available in times of drought	
	Reduces flood risk	End-user interviews, focus group discussions, key informant interviews, site assessments
5. Water services are affordable to users	Upfront cost	End-user interviews, focus group discussions, key informant interviews
	Funding mechanisms available	
	Financial support provided	
	Running costs	
6. Water services can be sustained over the long-term	Systems can be easily repaired	End-user interviews, focus group discussions, key informant interviews, sanitary surveys
	Community has the capacity to maintain systems	
	Systems are monitored over the long-term	
	Users feel a sense of pride and ownership over water systems	
7. Water services can be accessed equitably	Vulnerable user groups have been considered	End-user interviews, focus group discussions, key informant interviews
	Access to services for all community members	
	Women are actively supported to control water access	

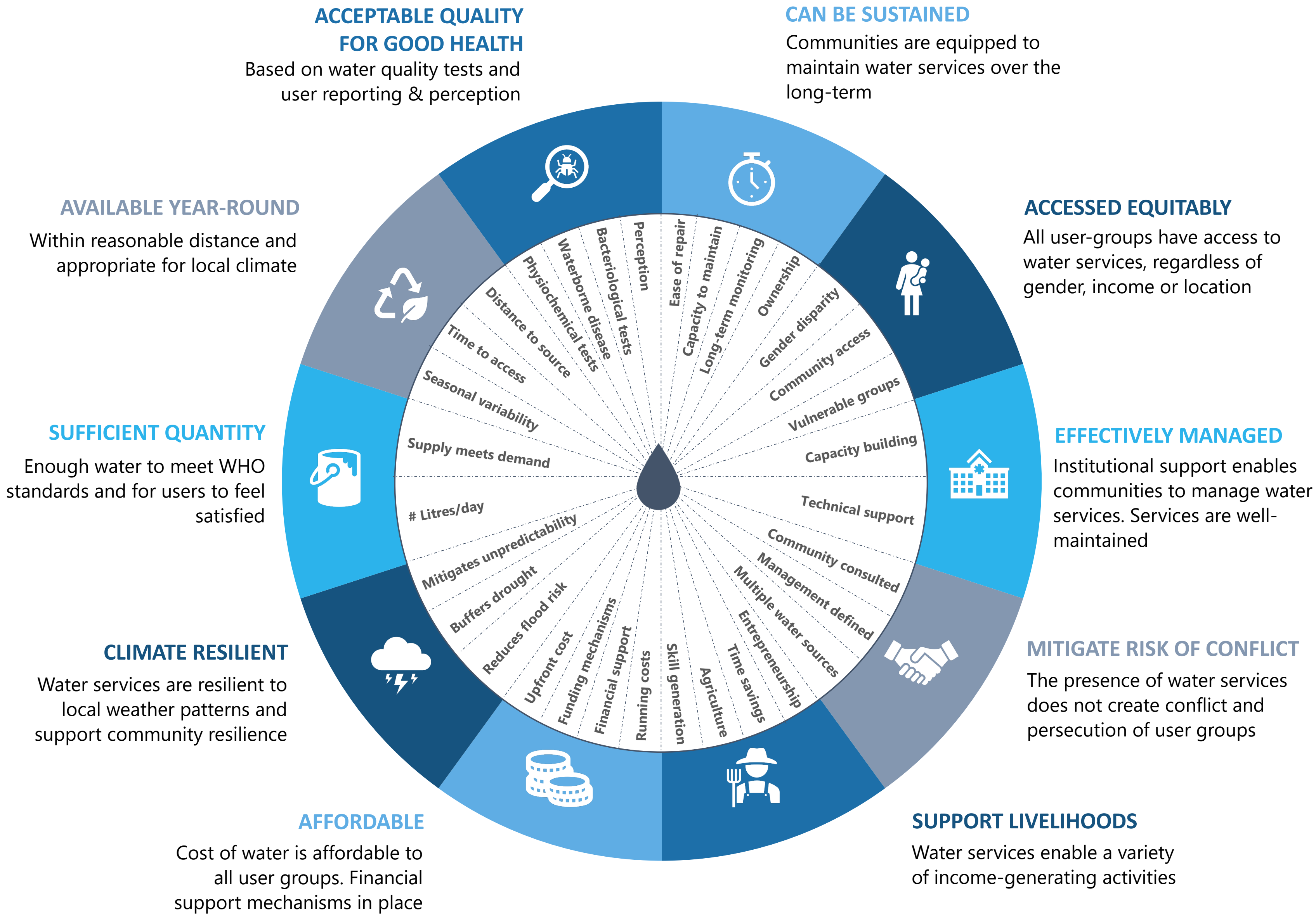
8.	**Water services are effectively managed**	Technical support is available Capacity building & training has taken place	End-user interviews, focus group discussions, key informant interviews, sanitary surveys
9.	**Risk of conflict over water services can be mitigated**	Multiple water sources are available Management roles are clearly defined Community has been consulted prior to installation	End-user interviews, focus group discussions, key informant interviews
10.	**Water services support local livelihoods**	Generates skills Supports agricultural activities Reduces time spent fetching water Supports entrepreneurial activities	End-user interviews, focus group discussions, key informant interviews,

Table 12 - Summary of water security goals, metrics and methods of assessment

4.4 Water Security Framework

In Figure 9, the ten water security goals identified through the stakeholder interviews are presented in the outer ring of the framework. The metrics that can be used to assess the degree to which decentralised water services are contributing to the attainment of these goals are presented in the central ring. The number of metrics per goals varies between two and four. Visually, the framework can be broken into ten ‘slices’. The outer section of the slice represents the goal, and the inner section includes the metrics used in the case study assessments.

Figure 9 – Framework for assessing the contribution of decentralised water services to community water security in low-resource settings



4.5 Chapter Summary

The framework developed in this chapter provides structure for the assessment of the sociotechnical drivers, barriers and outcomes of RWH use in Uganda. The framework was developed through findings from semi-structured interviews with thirty-two stakeholders from both the WASH sector and the case study communities in Uganda. The framework provides answers to research sub-question (1) '*How can the concepts associated with water security be framed to assess the sociotechnical outcomes of rainwater harvesting use in Uganda?'*

The literature review highlighted calls for further research to bridge the gap between the conceptualisation of water security and the implementation of techniques to improve water security. Developing a novel framework specifically for implementation in community settings in Uganda works towards bridging this gap. As the framework is designed to facilitate assessment, rather than just present concepts, these concepts are organised into measurable goals.

Building on previous research identified in the literature review, the water security goals go above and beyond solely describing the fundamental physical characteristics of water provision. Instead, they reference socioeconomic, environmental and technical outcomes. Traditional framings of water access focused on the physical characteristics of the human relationship with water. Is the water potable? Is there enough water? Is there adequate infrastructure to move and control water? The goals of water security presented in Figure 9 put the second-order, socioeconomic effects of well-managed water access at the forefront of the human-water relationship.

Referring back to the overarching research question, '*What are the sociotechnical drivers, barriers and outcomes of rainwater harvesting use in Uganda?',* through the development of this framework, a structure has now been put in place which allows for the identification of these drivers, barriers and outcomes.

5 CASE STUDY CONTEXT

This chapter provides background to the country and region of the selected case studies where the assessments of RWH interventions were carried out. The socioeconomic context, rainfall patterns and climate risks of Uganda are introduced. The interaction between the climate and the country's economy is also discussed. Existing water services and user demographics, along with information on adoption rates of rainwater harvesting in Uganda are presented. This chapter also introduces local information on Kabale and Mbarara, the two community case studies. Rainfall patterns and the delivery of RWH in each community is also presented.

5.1 Uganda Context

Uganda is located in East-Central Africa, bordered by the Democratic Republic of Congo to the west, South Sudan to the north, Kenya to the east, and Rwanda and Tanzania to the south (Africa Innovation Network, 2018). The World Bank classifies Uganda as a low income country, with just under 20% of the population living below the national poverty line (World Bank, 2016). Encouragingly though, the number of people living on less than \$2 per day has rapidly declined over the last decade. Uganda experienced strong economic growth in the 1990s and early 2000s at a rate of approximately 7% per annum (World Bank, 2017). From 2015–2016 the rate of economic growth slowed down to 4.5%. The World Bank (2017) attributes this slow-down to several factors, notably, adverse weather and the influx of refugees fleeing conflict in South Sudan.

Uganda's economic growth is predicted to slow due to the country's reliance on rain-fed agriculture, which remains a real downside risk to GDP growth (World Bank, 2017). Given that the agriculture sector employs more than 80% of the labour force within Uganda (Africa Innovation Network, 2018), the cascading effects of unpredictable rainfall variability have the potential to impact health, wellbeing, and livelihoods for much of the population.

5.2 Climate Risk in Uganda

In 2007, the Intergovernmental Panel on Climate Change identified Africa as one of the continents that is most vulnerable to climate variability due to multiple stresses and low adaptive capacity (Woltersdorf, Liehr & Döll, 2015). According to the United Nations International Strategy for Disaster Reduction (UNISDR), over 70% of natural hazards in Uganda are related to extreme hydrometeorological events (UNISDR, 2015). This risk has directly influenced migration patterns within the country. Since 1988, the country has seen internally displaced populations of up to 1.8 million people as a result of floods, landslides and droughts (UNISDR, 2015). This increase in risks associated with hydrometeorological events in Uganda has drawn attention to the need for improved climate adaptation within the country.

Grey & Sadoff (2007) explain that Uganda has a 'difficult hydrological legacy' – where rainfall is markedly seasonal, with short seasons of torrential rain followed by longer periods of drought. In a study carried out in 2017 by the World Food Programme (WFP) and the government of Uganda, it was reported that climate change is increasing the unpredictability and intensity of rainfall within the country, while simultaneously increasing the duration of droughts (Chaplin *et al.*, 2017). This unpredictability in the timing and length of droughts has led to water insecurity, undermining agricultural endeavours.

In an assessment of three regions of Uganda in 2015, Mayega et al. (2015) explain that the mere extension of a flood or a drought by as little as a month can mean the destruction of an entire crop (Mayega *et al.*, 2015). For farmers who rely on just one crop for livelihoods, this can have devastating effects. In response, the Ministry of Water and Environment (MWE) has concentrated efforts to mainstream climate change adaptation practices to prepare for changes in rainfall patterns (MWE, 2019). The efforts are needed, as there is evidence to suggest that the impacts of both floods and droughts are causing significant concern to populations in Uganda. Chaplin *et al.* (2017) found that nearly three quarters of respondents to their questionnaire (on the impacts of climate change on livelihoods) cited droughts/prolonged dry spells as a climate shock that had significantly affected their households in the last 5 years.

5.3 Water Services in Uganda

According to the WHO/UNICEF Joint Monitoring Programme, 95% of Uganda's urban population and 71% of Uganda's rural population has access to at least an 'improved water supply' where an 'improved water supply' is defined as a *'source that, by nature of its construction, adequately protects the water from outside contamination, in particular from faecal matter'* (WHO/UNICEF, 2015). While these figures seem acceptable, 'improved water sources' do not guarantee safe water. 'Improved water sources' meet the criteria for 'safely managed' drinking water service only if they are (1) accessible on premises (2) available when needed and (3) free from contamination. The charity Water.org estimates that only 39% of Ugandans have access to safely managed drinking water (Water.org, 2018).

In 2004, under the Poverty Eradication Plan, the water and sanitation sector was highlighted as a key area for development in Uganda (Republic of Uganda, 2008). Only 14% of Uganda's population has access to potable water managed by the National Water and Sewerage Corporation (NWSC), the majority of whom live in urban environments (WHO/UNICEF, 2015).

In a 2018 briefing paper published by Uganda's Budget, Monitoring and Accountability Unit (BMAU), it was estimated that Uganda was not on target to achieve Sustainable Development Goal 6: 'Ensuring availability and sustainable management of water and sanitation for all'. At current rates, the BMAU estimate that by 2030, Uganda will not meet any of the targets associated with drinking water and SDG 6 including percentage of population using an improved drinking water source, percentage of population using safely managed drinking water services located on premises, and percentages of drinking water samples that comply with national standards. Predictions of Uganda's failure to meet the UN's SDG Goal 6 targets by 2030 is largely attributed to a lack of financing, and poor management of rural water services (BMAU, 2019).

Figure 10 demonstrates the percentage of the rural and urban populations in Uganda served by piped and non-piped water. Coverage of piped water services is far higher for urban populations. Marginal progress has been made in serving rural populations with piped water. The percentage of the urban population served with piped water has actually decreased, this is likely caused by rapid urbanisation, where infrastructure services cannot keep up. In the absence of NWSC-provided water in rural environments, hand-dug shallow wells, groundwater collection schemes, gravity-flow schemes and rainwater harvesting are all practised by rural and peri-urban communities (Parker *et al.*, 2010). Typically, these decentralized water services in rural areas are funded by NGOs and private sector businesses (UN-Water, 2006).

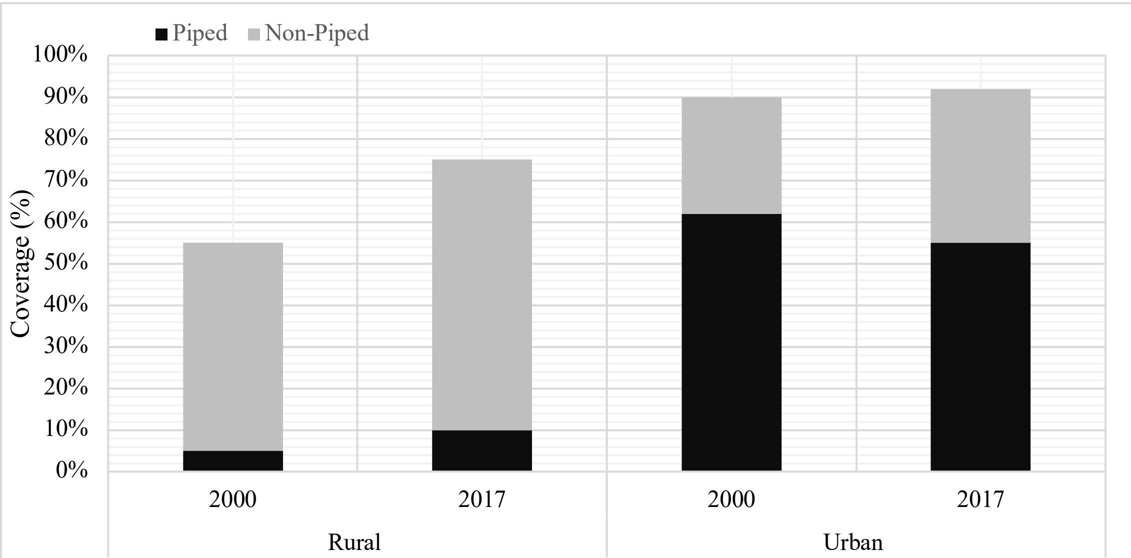


Figure 10 - Piped water coverage across Uganda in 2000 and 2017. Data provided by the Joint Monitoring Programme (2020)

5.3.1 Rainwater Harvesting in Uganda

Western Uganda's climatic conditions are well suited to rainwater harvesting as the bi-annual rainy seasons allow for two periods of rainwater collection each year. Nonetheless, only 1% of the rural population in Uganda uses RWH (Staddon *et al.* 2018). Both formal and informal rainwater harvesting practices are adopted in Uganda, with formal practices involving a 'system' which includes guttering, downpipes, and covered storage, and informal practices characterized by open containers (Kisakye, Akurut & Van der

Figure 11 - Ferrocement RWH tank (left) and HDPE RWH tank (right) in Uganda

Bruggen, 2018). Materials and designs for RWH storage in Uganda typically consist of either a ferrocement or a polyethylene tank as shown in Figure 11. Ferrocement tanks are preferred due to their longer life span and resilience to temperature changes. However capital costs for ferrocement tanks are higher (Rain, 2018). In addition, quality of construction of ferrocement tanks has a significant impact on their lifespan. Poor concrete compaction or incorrect sand-cement mixture are common causes for tank failure (Staddon *et al.* 2018).

In 2015, the Ugandan government introduced its ‘self-supply’ strategy, which encourages urban households to supplement conventional centralised water supply with local and easy-to-replicate solutions such as RWH (Staddon *et al.* 2018). There are broadly two types of user of RWH in Uganda, those who use RWH in addition to centralised water supply, and those who are not connected to municipal water supply, using RWH as a primary water source.

In urban areas, water services are expensive, and so populations look towards decentralised water supply to supplement their water access (Staddon *et al.* 2018). In rural areas, populations can choose community tap stands, gravity-flow schemes, RWH and shallow wells. Compared to alternative community water sources, rainwater harvesting (RWH) provides the advantage of supplying water directly to homeowners, reducing the labour time required to collect and transport water. Nonetheless, Staddon *et al.* (2018) suggest that difficulties associated with asset maintenance and water quality management could be barriers to the adoption of RWH in Uganda that have led to the low rate of uptake.

Staddon *et al.* (2018) believe that a better understanding of the factors that influence the adoption of RWH in Uganda can contribute to better policymaking by governments and development NGOs in Uganda to support RWH uptake. Potential drivers of uptake include financing mechanisms to subsidize the high capital cost associated with RWH, the presence of intermediary organisations to coordinate RWH system management, and better availability of cheap tanks (Danert & Motts, 2009a).

5.4 Case Study Area Descriptions

The two case studies were located in south-west Uganda where annual levels of rainfall are relatively high in both the urban and the rural study region. Mbarara (urban study) receives an average of 1373 mm of rainfall per annum and Kabale (rural study) receives an average of 1018 mm of rainfall per annum (Climate-Data, 2019).

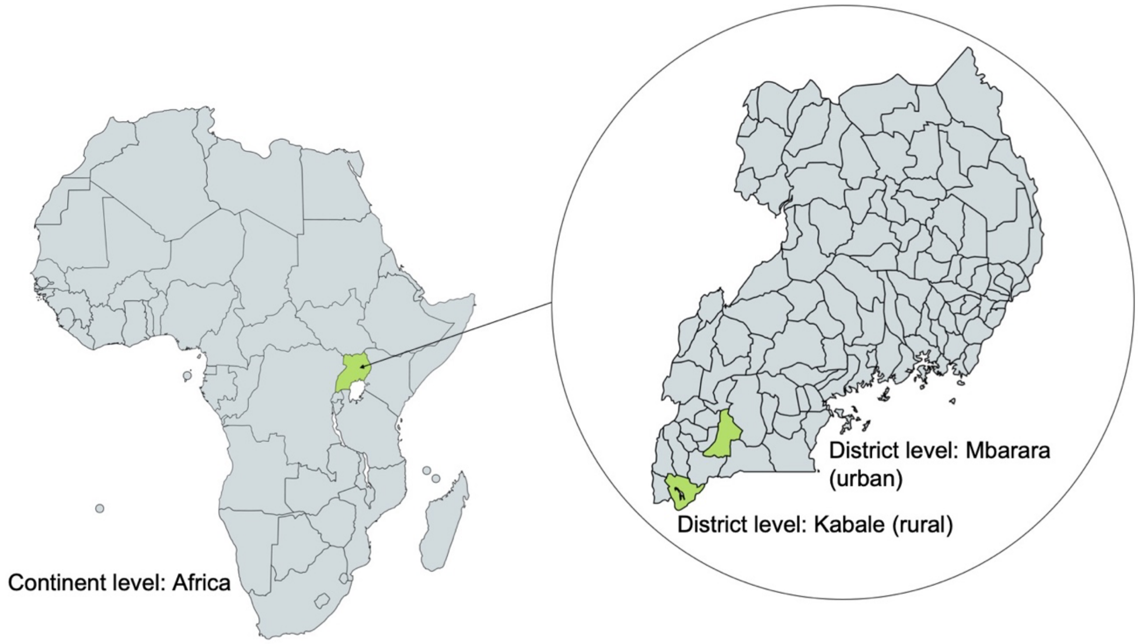


Figure 12 - Continental map of Africa (left). Uganda is located in the East Africa region. The district-level map of Uganda (right) shows the case study districts, Kabale (rural) and Mbarara (urban)

5.4.1 Kabale

Kabale district, bordering the Republic of Rwanda, is a highland district of Uganda, covering 1,864 km^2 of interlocking, heavily cultivated hills with an altitude ranging from 1,219–2,347m above sea level. Due to this high altitude, Kabale is colder than the rest of the country with average daily temperatures of 18^{o}C (Langan & Farmer, 2014). Kabale is one of four districts that makes up the Kigezi sub-region. Figure 13 demonstrates the typical rainfall distribution over a year (2010-2019 data) with wetter periods in March-May and October-December, and dry periods in June-September and January-February.

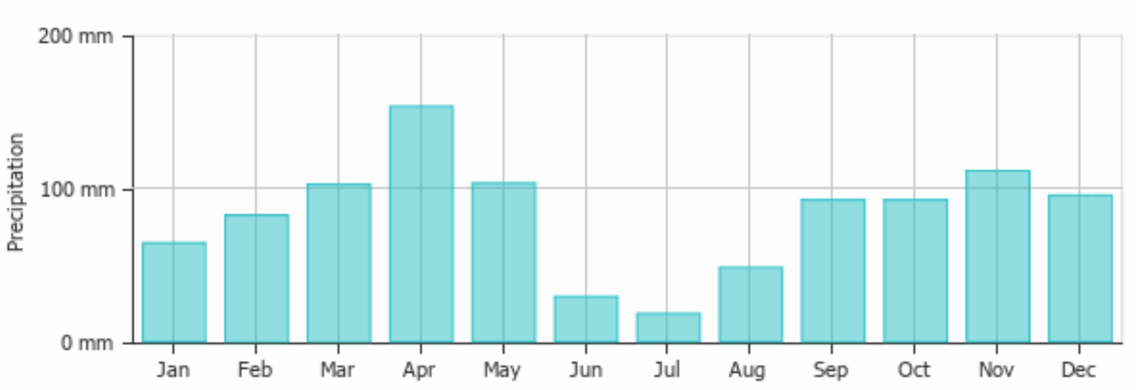


Figure 13 - Average monthly precipitation in Kabale, Uganda 2010-2019. Source: weather-and-climate.com (2020)

The 2014 census put the population of Kabale at 331,335 people. Despite being predominantly rural (91% of the population living outside the urban centre of Kabale), the district is densely populated. It must be noted that in 2015, two counties were separated from Kabale District by an Act of Parliament, and so the current population of Kabale is smaller than reported in the 2014 (most recent) census (Uganda Bureau of Statistics, 2014).

24.5% of the population cannot read and write, the average number of people per household is 5, and 81% of the adult population reported working (Uganda Bureau of Statistics, 2014). Only 26% of the district's population has access to piped water. Reported water sources include: water trucks, municipal water, RWH, boreholes, gravity-feed systems, and protected springs (Langan & Farmer, 2014).

Kabale is characterized by a population with '*low income, inadequate food and poor health'* (KDWSP, 2020). Although Kabale does not suffer from water scarcity, water security is an issue. As mentioned in the literature review, water stress does not just affect populations that suffer from physical water scarcity, it is often the consequence of human behaviours (such as overpopulation) that put pressure on water resources. A representative from Tearfund, a faith-based charity that has been partnering with the KDWSP for over 20 years, explains Kigezi's water insecurities:

> *'Kigezi is a non-water-stressed region with 8/9 months of the year with continuous rainfall. Kigezi isn't water stressed or water scarce, the problem*

> *is access and infrastructure. People are living up the hill and the journey to the water source is fraught with danger.'*

The community's relationship with water is also impacted by deforestation in the region, which has caused soil erosion leading to landslides, floods and water contamination (KDWSP, 2020). For a population that largely depends on agricultural endeavours for income, this failure of the local environment has had knock-on consequences for socioeconomic development. Due to recent landslides, communities have relocated from the bottom of the valley to hill-tops where the distance to the river (the primary water source) is approximately a 5 km round-trip along steep terrain.

Kigezi Diocese Water and Sanitation Project

In response to the water access challenges faced by communities in Kigezi, the KDWSP was set up in 1986 to address the lack of access to clean water. Recognising the benefits of RWH for the specific water access issues faced by the community from 2000, the KDWSP focused on service delivery through rainwater harvesting.

The KDWSP approach is to combine education and capacity building with the provision of new, decentralised, infrastructure. The KDWSP provides the materials needed for rainwater harvesting systems and tanks, but crucially, does not carry out the construction and installation. Instead, they train community members and homeowners on construction practices, with the aim of empowering community members with new skills. As community-wide demand for rainwater harvesting grows, the trained group can then re-deploy their skills to construct tanks for new customers, generating paid work for the trained group (KDWSP, 2020). In addition to RWH systems, the KDWSP also protect existing water springs and install gravity flow schemes that bring water to communal tap stands.

5.4.2 Mbarara Municipality

Located in Mbarara district, Mbarara municipality is the second largest city in Uganda after the capital, Kampala. In 2014, the Uganda Bureau of Statistics estimated the town's population size to be 195,318 (UBOS, 2014). It is the second largest city in Uganda after the capital, Kampala. 88% of the population report to be literate, and 77% of adults are working. A commercial and trading centre, the economy is predominantly based on business, trade and industry (UN-Habitat, 2012a). Despite the presence of infrastructure to provide municipal water supply, the Uganda Bureau of Statistics found that only 70% of the municipality's population had access to piped water (UBOS, 2014).

Figure 14 demonstrates the typical rainfall distribution in Mbarara over a year (2010-2019 data). Rainfall patterns are similar to Kabale, although, at 1373mm per annum, overall rainfall is slightly greater in Mbarara (Climate-Data, 2019).

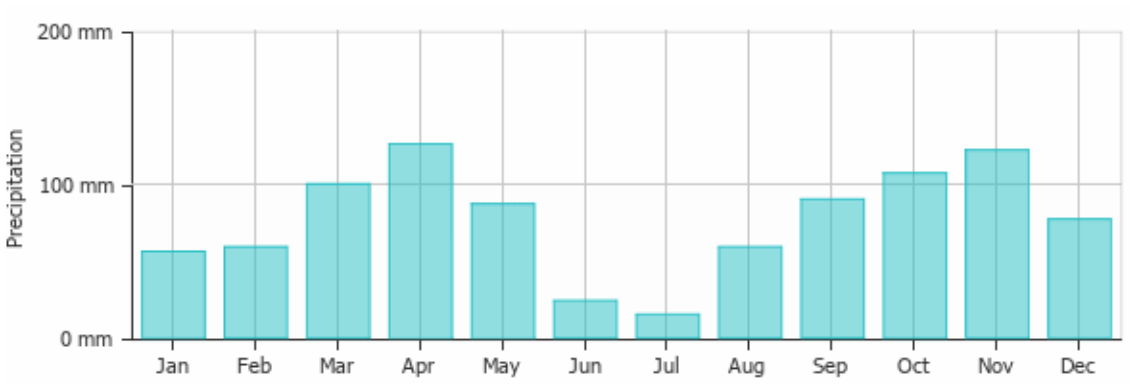


Figure 14 - Average monthly precipitation in Mbarara, Uganda 2010-2019. Source: weather-and-climate.com (2020)

Rainwater Harvesting in Mbarara Municipality

RWH is practised by a minority of urban residents. In Mbarara district as a whole, it is estimated that just 10275 people are served by RWH, which equates to approximately 4% of the population (MWE, 2020b). These users can be separated into formal (as with those urban users involved in this study) and opportunistic users, where little financial investment is made, and water is typically diverted into a jar or oil drum (MWE, 2020a). The question of why users with access to municipal water choose to invest in domestic RWH will be addressed in the Urban Community Case Study Chapter (7).

6 RURAL COMMUNITY CASE STUDY

This is the first of the 'two-case' case study chapters, where the findings from the application of the water security framework to the assessment of RWH sites in Kabale, the rural case study community, are presented. Answers to research sub-question (2) '*to what extent have specific rainwater harvesting interventions met sociotechnical water security goals in Ugandan communities?'* are presented in this chapter.

Household and institutional RWH sites from the community were assessed individually against each of the ten water security goals of the framework. The assessments were then combined to provide an overall indication of the extent to which rainwater harvesting has met water security goals in Kabale. Through the process of applying the water security framework to the rainwater harvesting sample sites, the drivers, barriers and outcomes of rainwater harvesting use in Kabale were identified, providing answers to the main research question.

6.1 Rainwater Harvesting Sample Sites

Ten RWH sites that represented a sample of typical cases of rainwater harvesting within the community were selected for this assessment. The sites were chosen by the researcher and the KDWSP. Six of the ten sites were domestic, and four were institutional. Table 13 provides detail on the individual site assessments.

The KDWSP normally construct the same size (4000 litres) RWH tank for domestic institutions, regardless of catchment size. They have a standard design for RWH systems that they replicate at all of their installations.

Site Name	Site Description	Number of users	Type of site	Tank Type	Roof Area (m2)	Tank Volume (m3)	Volume of water consumed/ day (m3)	Year of Installation	Price of RWH System (UGX)
Community centre	Community RWH system. Active management of the RWH system. Tank well maintained and regularly checked.	50	Institution	Ferrocement	100	10	1	2009	6,000,000
High School	Good quality RWH tank. Tank size appears to be too small for roof surface area.	700	Institution	HDPE	264	40	14	2016	13,000,000
Church 1	Large, central church. RWH system managed and serviced by the priest. Pivotal in providing community water supply in times of water stress.	100	Institution	Ferrocement	120	10	2	2012	6,000,000
Church 2	Relatively new RWH tank for the community church. Managed by the church leader.	50	Institution	Ferrocement	60	20	1	2017	8,000,000
Household Site A	Female head of household living with 2 children. Small on-site farm (arable & pastoral).	3	Household	Ferrocement	30	4	0.06	2012	3,000,000
Household Site B	Household of 2 adults and 3 children. Well maintained tank. A previous, unused RWH tank is visible on-site.	5	Household	Ferrocement	60	4	0.1	2015	3,000,000
Household Site C	Household with 8 family members. Head of household is a Pastor. Tank constructed by KDWSP. Household runs small arable farm.	8	Household	Ferrocement	60	4	0.16	2014	3,000,000
Household Site D	Household of 6. Tank was installed by KDWSP.	8	Household	Ferrocement	32	4	0.16	2017	3,000,000
Household Site E	Self-constructed mortar jar for a household of 6. Visible damage to the mortar jar and pipes.	6	Household	Mortar Jar	24	4	0.12	2010	1,000,000
Household Site F	Self-constructed mortar jar (informal RWH) for a household of 10 people.	10	Household	Mortar Jar	48	4	0.2	2011	1,000,000

Table 13 - Technical summary of RWH installations included in the Kabale case study (n=10)

This design includes High-Density Polyethylene (HDPE) guttering that collects water from rooftops and channels it into a ferrocement tank through a rudimentary large particle filter (Figure 15). The filter consists of a shallow bucket with small holes pierced into the base covered by a wire mesh filter that filters down to 200 microns. Finally, water enters the RWH tank, which is typically built at ground level. Water is stored in the tank and accessed through a tap at the base of the tank, where a soakaway collects grey water, which is water that is not recommended for drinking, but is unlikely to be contaminated with thermotolerant coliforms if the RWH system has been well-maintained and is functioning correctly.

Figure 15 - A 10,000 litre ferrocement RWH tank at a domestic site in Kabale, Uganda. Photo taken in July 2019.

6.1.1 Institutional Sites

The four institutional assessment sites included one community centre, one high school, and two churches. These sites served between 50-700 people with water. Of the four institutional sites, the school was the only site where water generated from RWH was not shared with the external community. One church served water to approximately fifty members of the public, the other to a hundred. As the sole water source for the churches, rainwater was used for cleaning, maintenance of grounds, cooking for church staff and drinking. At both sites representatives stated that during the rainy season, the tap stands remained open to the public with no restrictions. In the dry seasons, when it is common for no rain to fall for up to three months, water is rationed and typically only used by the church staff and occupants.

Three of the four sites had ferrocement tanks. Ferrocement tanks are constructed by hand and consist of a cement-rich mortar reinforced with layers of wire mesh (Loughborough University, 1992). Ferrocement tank sizes ranged from 10,000-40,000 litres. The alternative HDPE tanks, supplied in Uganda by Crestanks, can be bought in a variety of volumes from 50–24,000 litres. A common criticism of HDPE tanks voiced during the key informant interviews was that they are prone to cracking, and once damaged, the entire tank must be replaced, unlike with ferrocement tanks, where reparatory works can be carried out if cracking occurs. Three of the institutions used just one roof for catchment area, the other one used two roofs.

A 5000-litre HDPE tank costs 1,500,000 UGX (£318), just for the tank. A 20,000 litre HDPE tanks costs 6,696,325 UGX (£1417). A 40,000 litre ferrocement tank and system installation costs 9,000,000 UGX (£1,905) at an exchange rate of 4725 UGX: £1.

6.1.2 Household Sites

The six household sites had between three and ten inhabitants. Four of the sites had RWH systems installed under the supervision of the KDWSP between 2012 and 2017. At the other two sites (E &F), mortar jars, a low-cost, low-volume alternative to formal RWH systems, were used. These had been constructed by the homeowners themselves between 2009 and 2010. These homeowners had no technical training or financial support from the KDWSP. Homeowners reported using their water for cooking, cleaning, drinking and farming. All users reported that there are days during the dry season when the tank is empty, and that water was boiled for treatment before drinking. At sites B and C, users noted that they often had excess water in the rainy season. In these cases, they either shared water with neighbours or sold water for 500 UGX (11 pence) for a 10-litre jerrycan. At two sites users reported that, on occasion, the tank overflows with water during the rainy season.

At the four household sites installed under the supervision of the KDWSP, all tanks were 4000-litre ferrocement tanks. This is the standard size of tanks constructed by the KDWSP for a household. Each house had just one roof face in the catchment. Roof dimensions ranged from 24-60m^2. In Kabale, a 4000-litre ferrocement rainwater harvesting system installation by the KDWSP costs 3,000,000 UGX (£635). This includes roof guttering, tank, tap, soakaway, and rudimentary filter.

6.2 RWH and Community Water Security Goals

In this section the results from the assessments of the RWH sites against the ten water security goals are presented. Detailed information is provided on how the RWH interventions in Kabale have met each of the water security goals, and the final results are summarised towards the end of the chapter.

6.2.1 Acceptable Water Quality for Good Health

The bacteriological and physio-chemical tests carried out at each of the ten sites in Kabale provided insight into both the quality of water and how well the RWH system had been maintained. To supplement the water quality tests, qualitative data was collected through the end-user interviews to assess the users' perception of water quality (See Appendix I. for interview guide).

End-users were asked to provide a ranking of 1 (terrible) – 5 (excellent) of the taste and smell of water before boiling. End-users were also asked about frequency of the most common symptoms associated with waterborne disease - vomiting and diarrhoea. Of the six household sites, four of the respondents ranked the taste and smell of water at either 4 (good) or 5 (excellent). These were all users that had RWH systems installed with support from the KDWSP. The two household sites that had informal RWH mortar jars both ranked the taste and smell of water at 2 (bad) out of 5. The taste and smell of the water at the institutional sites was ranked at either 3 (ok) for the school and community centre or 4 (good) for both church sites.

Despite the significance of water quality in ensuring good health, water quality was not viewed as a priority by community members:

> *'For us, even if it is water running on the surface, if we can get that water, the quality is secondary. Water should be near and then after that, we can then talk about quality' (KI02a).*

The WHO's guidelines on drinking water quality classify thermotolerant coliforms (TTCs) into four risk categories: conforms to guidelines (<1 CFU/100ml), low risk (1-10CFU/100ml), medium risk (>10-100CFU/100ml), and high risk (>100 CFU/100ml) and state that TTC count per 100ml should be zero (WHO, 2008).

Overall, 20% of sites tested positive for TTCs in the WHO medium risk category: 10 - 100 CFU/100ml (Table 14). At all sites where TTCs were identified, the water had a turbidity above 5 NTU, and so failed to meet both TTC and turbidity standards (WHO, 2008). Presence of TTCs is often related to seasonal influences such as rainfall (WHO, 2008). Nonetheless, both sites tested positive for TTCs in the 2018 visit (wet), did so also in the 2019 visit (dry). The pH recorded at all of the test sites lay in the WHO's acceptable range of 6.5 - 8.5. All of the RWH systems installed with the supervision of the KDWSP conformed to WHO guidelines. The two informal RWH rural sites with mortar jars both tested positive for TTCs.

Site Name	pH Median (n=2)		Turbidity (NTU) Median (n=2)		CFU/100ml Mean* (range) (n=4)	
	Dry season	**Wet Season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**
Community centre	6.8	7	0	0	<1	<1
High School	7	6.9	0	0	<1	<1
Church 1	7.2	7.4	0	0	<1	<1
Church 2	8.1	8.2	0	0	<1	<1
Household Site A	6.9	6.9	0	0	<1	<1
Household Site B	8.1	8	0	0	<1	<1
Household Site C	6.8	6.9	0	0	<1	<1
Household Site D	8.1	8.2	0	0	<1	<1
Household Site E	6.9	6.9	20	20	25.2 (16 – 40)	39.8 (28 - 50)
Household Site F	6.9	6.9	0	20	<1	64.67 (36 - 120)

Table 14 - Physiochemical and bacteriological test results for RWH samples from institutional and domestic sites in Kabale Uganda (n=10). *Geometric mean

Reports of waterborne disease (in response to the question: how many times a month do you have vomiting or diarrhoea?) varied between end-users. Four of the ten end-users reported vomiting or diarrhoea. Two of these were at the mortar jar sites, and two were at institutional sites.

Focus group participants also reported vomiting and diarrhoea but '*once or twice a year'* was the most frequent response. These results must be viewed with caution as often interviewees do not want to discuss sickness in a public forum. In addition, not all cases of sickness can be directly attributed to poor water quality. Further research should be carried out to identify the relationship between water quality and incidences of sickness among community members.

The water quality tests along with the taste and smell perception results indicate that overall, the sites that were linked to the KDWSP had good water quality, with all sites meeting WHO standards. This suggests that the KDWSP's approach has led to positive results for good water quality. The poor water quality at the informal sites may be due to poor maintenance practices of RWH systems.

6.2.2 Available Year-Round

The seasonal nature of rainwater harvesting is one of the biggest barriers to its use as a primary water source. Typically, tanks appeared to be full during the rainy season and empty during the dry season. All ten end-users stated that their tanks were empty for at least three months a year. This was confirmed by the water balance models, the results of which are presented in Figures 16 and 17. In the absence of rainwater, alternative water sources were sought such as the river or gravity-feed schemes introduced by the KDWSP.

The two churches conducted strict control and management practices to ensure water remained when most needed:

> *'If it rains every other day and the tank can be filled, normally that would last for two months when the dry season begins, then we close all the tanks. If we had a bigger reservoir, we would be better able to evenly distribute the water' (EU03).*

Several users stated that the drawbacks associated with the lack of year-round availability of rainwater were offset by the benefits of on-site water access. A lack of proximity to water sources was cited as a significant incentive for domestic RWH. In the community in question, prior to the installation of RWH systems, the average time spent fetching water daily was between 2 and 5 hours. Users stated that the walk to the river down the valley would take on average 3 hours (but longer for elderly members). At community water points, queues of up to 40 people were the norm.

The time-consuming nature of water collection was felt most acutely by women and children. This is largely due to engrained gender roles within the community where women and children are charged with the collection of water. One of the critical socioeconomic consequences of this 'lost time' is absence from school:

> *'Sometimes the [children] have to really go down the hillside to fetch the water and then by the time they get back home, its midday, and they're too late for school' (Focus group participant).*

On-site availability of water also improved users' hygiene practices, which, in turn, gave mother's confidence that their children could be presentable for school. Several mothers stated that they often would not send their children to school if they felt embarrassed that they did not have enough water to maintain good hygiene practices: '*clean clothes, hair and nails' (KI07b).*

All community members cited 'morning' as the time they went to fetch water because there were no queues, and temperatures for walking were manageable. This loss of available time in the morning had a cascading effect on the day's activities. Many of the focus group participants stated that morning was the time they had the most energy and could be the most productive for agricultural activities. The renewed availability of this time following the introduction of domestic RWH systems meant that women felt they could be more productive during the day. 'Productivity' not only referred to income-generating activities, but also to general domestic chores such as cooking and cleaning.

6.2.3 Sufficient Quantity

The water balance models provided insight into whether the RWH tanks were sized appropriately for the catchment area and the water demand of the users. Daily rainfall data for the year from 1st July 2018 – 1st July 2019 were taken from Tutiempo, an online database that provides historic daily rainfall data provided by local weather stations. Kabale weather stations were selected (Tutiempo, 2020). Simulations of the volume of water in the tank over the 1-year period were generated to assess how often supply failed to meet assumed demand, whether the size of the tank was suitable for the catchment area and whether RWH could provide year-round water for users in the region.

The roof area, number of roofs in catchment, and tank size were measured for each of the 20 sites during the site inspections. Daily water demand (D_t) was calculated based on the WHO recommendation of 20 litres/person/day x number of people that used the RWH system. An assumption that all demand would need to be met from water produced from RWH was built into the model.

Figure 16 shows the volume profiles for the RWH tanks at each of the four institutional sites. Ideally, water provided by RWH would serve the users' minimum water needs of 20 litres/person/day, however, none of the institutional tanks were able to service this demand.

On average, over the 1-year simulation period, institutional RWH tanks were empty for a mean number of 170 days a year (n=4). As can be seen in Figure 16, the community centre was the only institution that had a buffer of water supply in the October-January wetter season. The RWH systems at the high school and both of the churches did not provide any buffer of water supply for users at any point throughout the year. This may be because the level of demand is so significant with a population of 700 pupils served daily by the school's RWH system. The school also relies on municipal water supply to serve their population; however, this supplementary supply was not included in the model. In the case of the school, with such a significant daily water demand (at least 14,000 litres), RWH is most appropriate as a supplementary water source.

In the case of the other three institutional sites, Figure 16 suggests that the RWH systems cannot provide enough water to meet demand. With tanks empty for nearly 50% of the year, the RWH systems installed on these institutions do not appear to have the capacity to supply the estimated water needs of their users. Overflow or spillage was not an issue at any of the institutional sites.

Interviews with end-users and institutional site managers identified that, for the three institutions that supplied water to the community, members of the public were likely to extract approximately 10 litres/day of water rather than the 20 litres/day recommended by the WHO, which would reduce the number of days the tanks were empty. There were two reasons for this. First, end-users cited a widely available 10-litre jerrycan as the standard vessel for transporting water by hand, and second, because water volumes extracted by the public were controlled by the site managers, particularly in the dry season. At all three sites open to the public, site managers limited water access during the dry season when water levels were low.

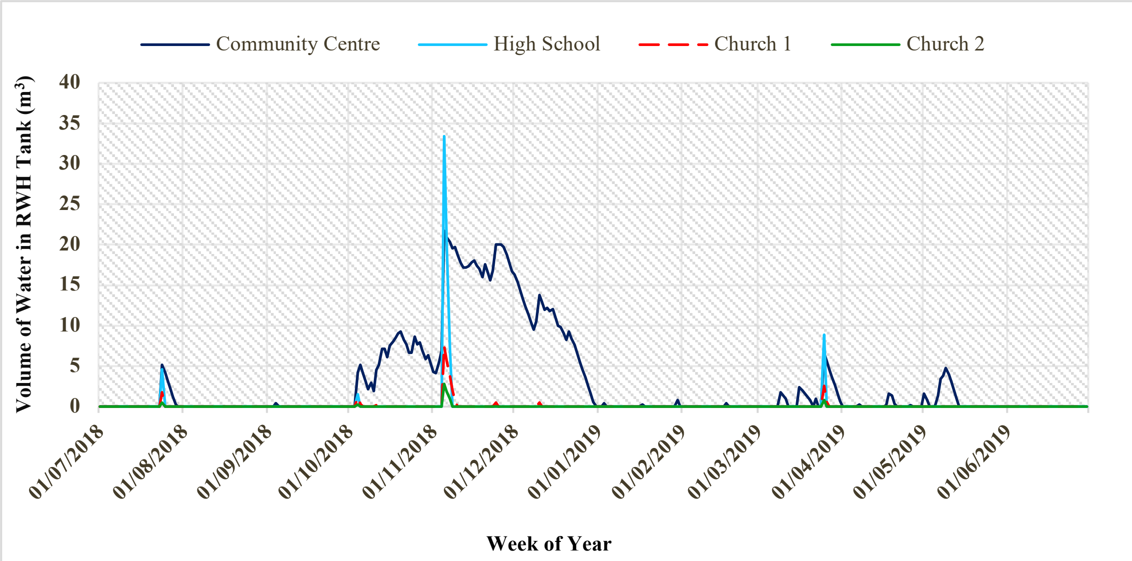


Figure 16 - Results from water balance simulation showing volume of water in RWH tanks at four institutional sites in Kabale between July 2018 and June 2019

Figure 17 shows the volume profiles for the RWH tanks at each of the six household sites. In comparison to the institutional sites, the household sites satisfy household water demand on many more days of the year. The mean number of days the tanks were empty over the 1-year simulation period was 103. However, three of the six tanks overflowed on at least eight days of the year. Overflow is typically caused by a tank that is too small for the catchment area and can be prevented by increasing the size of the RWH tank for larger roof catchments. End-users also reported destruction of local crops resulting from overflowing tanks. At all six sites, the RWH storage tanks had a volume of 4000 litres. The catchment areas ranged from $24m^2$ – $60m^2$ and demand ranged from 60 litres/day – 160 litres/day.

Taking Church 2 as an example, with a roof area of $60m^2$, the daily volume of water in the tank was calculated by using the formulas presented in Chapter 2, Section 2.7.5. Volume of water consumed per day (D_t) was calculated by multiplying the number of users at the site (50) by the daily water demand (20 litres/per person). It must be noted that this is very much a minimum demand, which can satisfy only the most basic water needs. Had a higher daily water demand been selected, the number of days a year the RWH tanks were empty would have been higher.

Daily water demand = number of users at the site (50) x daily water demand (20 litres/per person) = 1000 litres = $1m^3$

Total volume of water harvested on a given day (I_t) = rainfall x roof area x water loss due to evapotranspiration (0.8). On 24th July 2018, 0.031m of rainfall fell, so for this day:

$$I_t = 0.031 \times 60 \times 0.8 = 1.49 \text{ m}^3$$

The volume of water in the tank at the end of the day = $I_t - D_t$ = 1.49 – 1 = **$0.49m^3$**.

As less rain had fallen than was consumed during the previous days of the simulation, $0.49m^3$ was the entirety of the volume of water in the tank at the end of the day. On days where a 'buffer' of water had built up, this volume was added to the daily volume of water harvested. This provided an estimate of the total volume of water in the tank at the end of each day included in the year-long simulation.

The driest months in this 2018/2019 period in Kabale were from June-October. As expected, this is when the simulation suggested the tanks would be empty for the highest number of consecutive days. As with the institutional sites, end-users actively attempted to conserve water for the dry season, but several end-users reported lack of storage as a barrier to managing water supply.

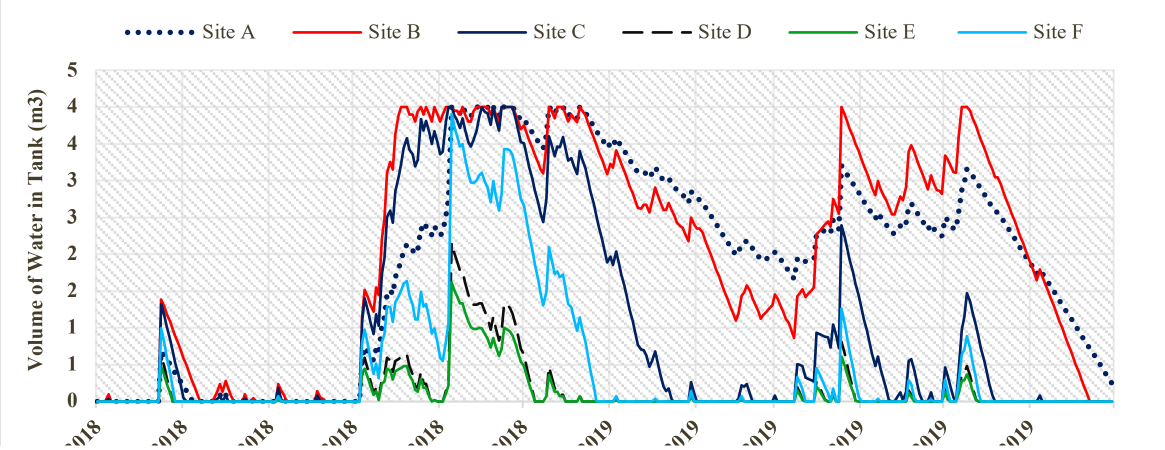


Figure 17 - Results from water balance simulation showing volume of water in RWH tanks at six household sites in Kabale between July 2018 and June 2019

Important household activities that used water included '*cooking, drinking, bathing, washing and cleaning the home'*. Those focus group participants and end-users with access to a RWH system spoke of a '*new freedom'* after the tank was installed. When they did not have access to household water, focus group participants explained that they were '*pressed to make a choice between cooking, bathing, or washing clothes*.' As a result, community members explained that their personal hygiene greatly improved when water access was no longer limited.

6.2.4 Climate Resilient

The community reported having faced climate challenges for over a decade. From 2009, extreme flooding caused hundreds of households to relocate from the bottom of the valley to further up the hillside to avoid the impact of landslides. The cause of flooding was cited by focus group participants as '*changing climate'* and '*deforestation*'. This relocation was one of the primary drivers of the widespread adoption of RWH, as on-site water access was desperately needed once the distance to the primary water source (river) greatly increased.

The focus group participants were asked about their perception of the impacts associated with climate change. '*Extreme weathers, irregularity and unpredictability'* were all cited as climate challenges:

> *'The rain is not regular and when it comes, it is very destructive, and it does not come in the season it is expected to come. When it has come, it's too much and destroys the roads, homes, the gardens' (Focus group participant).*

Shifting rainfall patterns were cited as '*highly disruptive' (KI06)*, with rainfall occurring in recent years in July (typically a dry month), and drought occurring over the December to February period, a time when rainfall was typically reliable. The impact of this unpredictability was felt most significantly on crop growth. Knowledge on planting techniques and timings had been passed down through generations, and these practices were based on historical rainfall patterns. The rapid change in these patterns impacted both the timings of crop plantation and the type of crops that could be planted. Rainwater harvesting was cited as a method to overcome the impacts of this new unpredictability as '*buffer water' (KI06)* could be used when rainfall failed. This, however, depended on the proactive conservation of rainwater from previous rainfalls.

Crop failure caused by flooding was cited by community members and 20% of end-users as a negative climate impact. However, far more prevalent were reports on crop failure as a result of drought:

> *'there are crops which survive in too much rain which you can live on, but very few crops can withstand drought'(KI10a).*

Community members had a clear understanding of how RWH could mitigate the impacts of drought if supply was managed so that a 'buffer' was available during the dry period. In contrast, RWH's potential to reduce surface runoff was not cited as a benefit by any end-user or community member.

The focus groups revealed that there were many misconceptions associated with climate change. Some community members cited a strong link between cases of cancer within the community and a changing climate but could not provide a coherent argument for the correlation between the two. Of course, the intention of the qualitative data was not to collect scientifically robust data. Instead, the *perception* of the community was sought. Nonetheless, the confusion associated with climate change highlights the need for clear messaging when discussing water and climate.

6.2.5 Affordable

Widely stated among interviewees was that the biggest barrier to the adoption of RWH was the high capital cost. In Kabale, a 4000-litre rainwater harvesting system installation costs 3,000,000 UGX (£635). Given that the median monthly rural wage in Uganda is 120,000 UGX (£25), the cost of RWH is beyond the means of most rural users (UBOS, 2017). If rural inhabitants are to benefit from RWH, financial support is essential. The KDWSP recognise this and provide funding for '*70% - 90% of the cost, depending on the income level of the user' (KI03)*. This means that for the poorest users, the financial contribution is reduced to as little as 300,000 UGX (£64). The KDWSP believe that the end-user's financial contribution also helps to ensure a sense of ownership of the technology. They believe that this improves the lifespan of RWH systems:

> *'Normally, where people make a small contribution, the system lasts longer. If it is given for free, maybe 10% will be working after 3 years, but if they have made a contribution, even if it is a 10% contribution, the families keep the system in working order'(KI04).*

The cost of RWH must be viewed in comparison to the cost of alternative water sources. In the absence of household RWH, alternative water sources include the river at approximately 5km distance (free), gravity-feed installations (free), community-provided rainwater (free) or jerrycans of water sold by vendors. The no-cost water sources come with complications and time penalties: long queues or treks to the source. As a result, the majority of community members resorted to buying jerrycans of water.

A 20-litre jerrycan of water costs 1000 UGX (21 pence). For a 5-person household, this amounts to an approximate cost of 5000 UGX (£1.05) per day, or £383 a year (based on the WHO minimum requirement of 20 litres/person/day). In under 2 years the initial capital cost of RWH is less than the cost of jerrycan purchases. The long-term financial benefit of the RWH system is evident. This notion was well accepted by end-users, and the potential for water provided on-site for free was mentioned as a high-driving factor for RWH adoption.

The cost of maintenance of the systems was regarded as low, with maintenance activities that required cost including *'repairs to tanks, replacement of guttering, filters and roofs' (EU06).* The mean annual cost of maintenance for institutions was 183,094 UGX (£39). The range was £31 to £48. The mean annual cost of maintenance for households was 24,413 UGX (£5). The range was from £2 to £8. Female members of the focus groups who had been trained in RWH maintenance stated that their maintenance costs were low because they had the capacity and knowledge to build and maintain the systems and so only had to pay for raw materials when conducting repairs.

Despite the high capital cost of RWH, the cumulative spend on RWH over a 20-year period for a household in Kabale comes to 3,449,250 UGX (£730). This assumes an initial cost of 3,000,000 UGX (£635), with a running cost of 24,413 UGX (£5) per annum. If that household were to source water solely from locally available jerrycan vendors, their total spend over 20 years would be 36,193,500 UGX (£7660).

In reality, most users adopted a hybrid model – using RWH where possible and supplementing this with water from vendors for the (median) 103 days a year the RWH tank was estimated to be empty. Figure 18 demonstrates that with this hybrid model of household RWH harvesting, supplemented by water supplied by a local vendor, after 20 years the cumulative spend on water is 13,655,959 UGX (£2890), saving 22,537,541 UGX (£4770) when compared to sourcing water solely from local vendors. This value however does not account for discount rates, and despite the savings over a 20-year period, the capital cost of RWH is still a significant barrier to adoption.

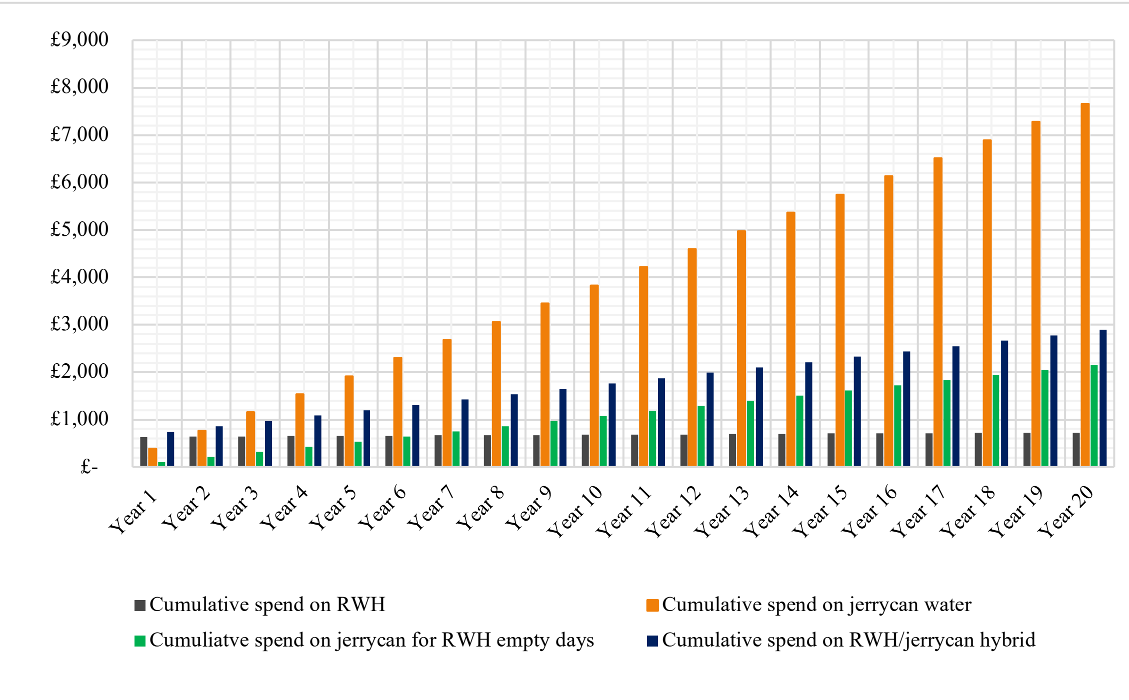


Figure 18 - Household water costs (assuming a 4000 litre ferrocement tank) over a 20-year period for RWH or locally available 20-litre jerrycans

6.2.6 Can be Sustained

Whether RWH systems can be sustained to reach their design lifespan depends on both the ease of repair of a system, and the user's capacity to maintain the system. A Likert scale was presented to end-users with the question 'On a scale of 1-5, how confident do you feel in maintaining your system?' 1 (not confident at all), 2 (under confident), 3 (fairly confident), 4 (very confident), 5 (extremely confident). Seven of the ten end-users responded with either a 4 (very confident) or 5 (extremely confident). All four homeowners who had been trained by KDWSP on tank management replied with a 4 or 5.

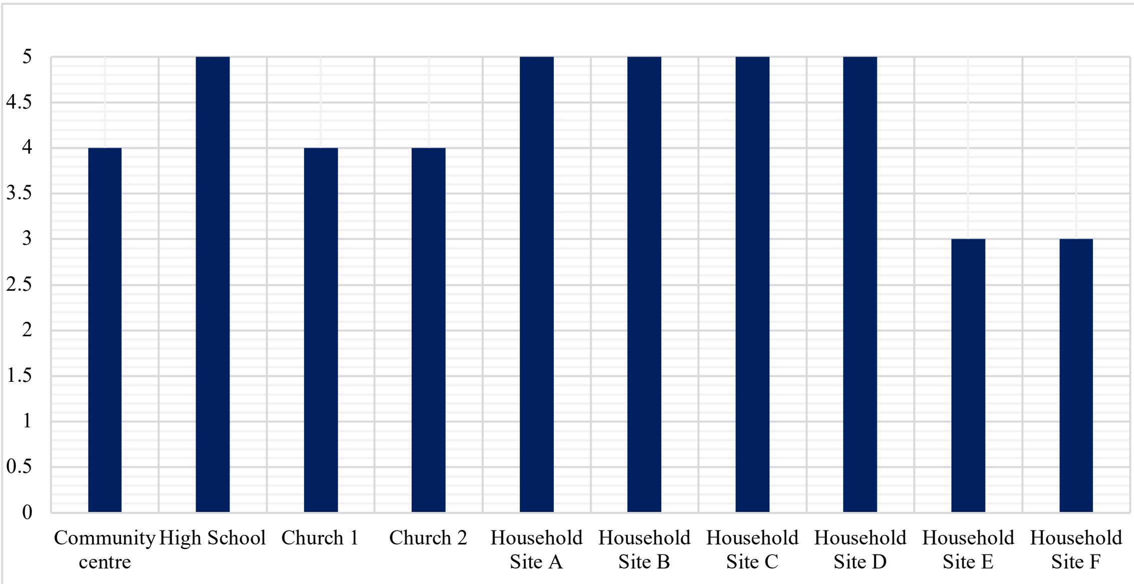


Figure 19 - Likert Scale responses (1 to 5) for ten RWH assessment sites in Kabale. On a scale of 1 to 5, how confident do you feel in maintaining your RWH system?

At the two sites with mortar jars (E & F), end-users responded with a 3 (fairly confident) out of 5. However, the water quality tests, and site assessments demonstrated that upkeep and water quality of these systems was poor. The confidence of the end-users at the sites supported by the KDWSP suggests that the proactive role of the intermediary organisation (KDWSP) has a positive impact on both the users' confidence and ability to maintain systems, and therefore the potential for longevity of the systems.

The RWH systems were specifically designed with ease-of-maintenance in mind. Preference for ferrocement tanks over HDPE tanks was largely based on the ease with which ferrocement tanks could be repaired in contrast to HDPE tanks, which, when cracked, needed to be replaced. Elements of the RWH system such as the mesh filter were sourced and built locally for approximately 20,000 UGX (£4.23), and so could be easily repaired and replaced.

All of the systems involved in the assessment were installed between 2009 and 2017. The KDWSP stated the design life of the systems is *'20-30 years, if well-maintained'(KI03)*. This long lifespan created a feeling of security among users, with focus group members explaining that they had '*less anxiety'* about where water would come from in the future. The assessment highlighted that sustainability of RWH systems is strongly linked to the effective management of the systems, which, in turn is linked to capacity building and educational activities.

At the institutions, a lack of clearly defined roles of responsibility was cited as a barrier to maintenance. In contrast '*pride of tank' (EU05)* was cited as an incentive to regularly maintain tanks at the household sites. One user explained that:

> *'Taking care of the system is like taking care of a baby, you make sure you do it well, because then it will last forever' (EU08).*

The KDWSP stated that, when choosing an institution on which to install RWH, an organised, structured group of water committee members was a pre-requisite. When a maintenance group was formed specifically around a water project, their experience suggested that once the project was physically completed, the group would disband, and maintenance tasks would not be completed. In contrast, where a group was already organised and had approached the KDWSP for a RWH system, the system was much more likely to be sustained over the long-term.

Existing committee members were trained not only on construction and maintenance of RWH, but also on management tasks such as how to *'take records, who is in charge of receiving materials, issuing materials and collecting payment for upkeep' (KI04)*. This training and institutional support from the KDWSP appears to support the sustained upkeep of systems. Community members cited '*a clear understanding of maintenance roles' (EU01)* as explanation for the success of maintenance practices when a pre-existing organisational structure was in place.

6.2.7 Accessed Equitably

Not all user groups benefit from community water services. Ensuring marginalised groups have access to water services was identified as a priority for water security among the stakeholders interviewed for Chapter 4. During the focus groups, the community identified marginalised groups as '*women, children, older people, frail people'* and '*those that lived very remotely' (Focus group participant)*.

Community-cohesion among the focus group participants appeared strong, and where users had RWH systems, and their neighbours did not, members cited '*water sharing'* as common practice. In some cases, end-users would charge for this water, but predominantly water appeared to be shared with close neighbours at no cost.

The largest demographic disparity identified by the group was between women and men. Women did not have more difficulty accessing water than men, but rather the women in the focus group felt that the burden of water collection fell to them to a disproportionate degree. When asked why, one woman explained:

> *'There is some unfairness especially when men sit back and they expect a woman to collect firewood, to go and fetch firewood, fetch water and come and do all the domestic chores, cooking and he's seated like a king waiting to be served' (Focus group participant).*

This burden is driven by cultural norms engrained in local and national society. The men of the group explained that it would be emasculating to collect water, as it was regarded community wide as '*women's work'.* Consequently, the time taken to collect water, and the risks associated with this collection, disproportionately impacted both the livelihoods and well-being of women over men.

This imbalance has been clearly identified by the KDWSP and attempts to minimise the gender inequality associated with water management were embedded into the design of their RWH programme. The training that the KDWSP carries out to build users' knowledge on RWH construction and management is specifically aimed at women. Typically, eight times the number of women than men are trained in each training cycle. A KDWSP representative explained:

> *'It makes sense because women are in charge of the management of water, and so we should give them the knowledge and expertise to construct and maintain their RWH systems' (KI05).*

Homes that were run by couples explained that cleaning practices were shared between the men and the women, where women carried out the cleaning of '*guttering, soakaways, and filters' (EU06)* and men cleaned the inside of the RWH tanks. This culture of shared responsibility was created by the KDWSP and was replicated among all the three homes in the assessment that were run by a couple. In this way, the RWH programme had attempted to reduce pre-existing gender inequality.

The potential of the RWH programme to reduce pre-existing socioeconomic inequalities within the community is less evident. Given the links between enhanced socioeconomic status and RWH those that do not receive a RWH system may be further left behind from the community's socioeconomic growth. The KDWSP attempts to overcome this challenge by subsidising the cost of systems based on the income of the household. However, there were members of the community who explained that they still could not afford the subsidised price of the system.

The institutional RWH installations allowed poorer users to access water, when otherwise they would not have been able to afford the 300,000 UGX (£64) to cover the 10% of the household system cost. For this reason, community systems can benefit poorer community members, but when asked whether members would prefer a RWH system at home or on a community institution, the unanimous response was '*at home'*. This was because community RWH installations suffered from similar downfalls to pre-existing water services such as *'queues, long distances to carry water and lack of ownership' (Focus group participant)*.

6.2.8 Effectively Managed with the Support of Institutions

Management of RWH systems includes both maintenance (repairing external cracks in tanks, roofs and guttering) and cleaning (gutters, filters, roofs and tanks). The sanitary survey scores provide a good indication of how well a system has been maintained and where there is risk of contamination (ROC) to rainwater. Table 15 provides the overall ROC score for each of the sites.

Sanitary surveys for rainwater harvesting consist of 10 questions with 'yes' or 'no' answers. 'Yes' answers indicate that there is a risk of contamination. Each 'yes' is assigned 1 point. Each 'no' answer scores zero points. The maximum risk of contamination (ROC) score for RWH is 10. A higher score corresponds to more hazards present during the survey and thus a greater risk that drinking water is contaminated by faecal pollution.

The four institutional sites and household sites A-D were all installed in parallel with training on construction and management by the KDWSP. These sites all exhibited low ROC scores, indicating that the systems were well managed and maintained. Household sites E and F consisted of self-constructed mortar jars, a low-cost, low-volume alternative to formal RWH. These sites exhibited high ROC scores in both the dry season and the rainy season, indicating that they were poorly managed. Interviews at these sites demonstrated that end-users had not undertaken any formal RWH training and at both sites, users responded that they only felt 'fairly confident' with carrying out maintenance tasks.

Table 15 shows the number of sites in Kabale presenting with each risk from the sanitary survey. The most common risks across the test sites were a lack of first flush (dry=10, wet=10, n=10), dirty guttering (dry=5, wet=3, n=10), and inadequate drainage (dry=7, wet=7, n=10). All of the RWH systems installed by the KDWSP had a basic large particle filter (as seen in Figure 20): a low-cost, mesh coarse leaf filter at the storage tank opening. Sites E and F (the two mortar jar sites) did not have a pre-filter installed.

Site Name	Site Description	ROC Score, Dry Season (max 10)	ROC Score, Wet Season (max 10)
Community centre	RWH system installed on a community centre. Active management of the RWH system. Tank well maintained and regularly checked.	3	3
High School	Large RWH tank serving a school. HDPE tank size appears to be too small for roof surface area. Water not shared with wider community outside of school.	3	2
Church 1	Large, central church. RWH system managed and serviced by the priest. Pivotal in providing community water supply in times of water stress.	3	3
Church 2	New RWH tank for the community church. Managed by the church leader, who states that in the dry season water is rationed, otherwise the community is free to use as they like.	1	2
Household Site A	Female head of household living with 2 children. Small on-site farm (arable & pastoral). RWH water used for domestic chores, drinking and farming.	5	4
Household Site B	Household of 2 adults and 3 children. Well maintained tank. A previous, unused RWH tank is visible on-site. This was decommissioned and was constructed without the support of KDWSP.	1	1
Household Site C	Household with 8 family members. Head of household is a Pastor. Tank constructed in 2014 by KDWSP. Household runs small adjacent arable farm. Family reports farming is only made possible due to the presence of the RWH tank.	2	3
Household Site D	Household with 6 family members. Tank was installed in 2017 by KDWSP. Prior to tank installation women and children report spending 5 hours a day fetching water. The homeowner often sells water from RWH for local construction projects.	4	2
Household Site E	Self-constructed (no training) mortar jar (informal RWH) for a household of 6 people. Visible damage to the construction and small jar volume.	8	9
Household Site F	Self-constructed (no training) mortar jar (informal RWH) for a household of 10 people. Supplementary water supplied by community church RWH system.	6	9

Table 15 - Risk of Contamination (ROC) scores for RWH institutional and household sites in Kabale (n=10)

The pre-filtration technique adopted at several of the test site locations was basic and included only a low-cost, mesh coarse leaf filter at the entrance to the storage tank. This type of filter has the ability to filter only larger particles and debris from entering the tank.

Nothing smaller than 200 microns will be filtered by this type of coarse filtration screen. Nonetheless, filtration screens are seen as a reliable way to effectively reduce contamination (Mosley, 2005).

Figure 20 - A locally made water filter with plastic bucket and 5 mm wire mesh. Photo taken July 2019

None of the sites had a first flush installed. The first flush excludes the first rainfall to hit the roof, meaning that easily mobilised dirt, debris and contaminants are excluded from use. It is commonly agreed that a first-flush diversion system, used to divert the first 0.8-3.5mm of rainfall away from storage, can reduce the presence of contaminants in rainwater. The rationale is that the initial rainfall washes away high concentrations of contaminants from the catchment surface (Amin, Han & Alamoudi, 2011; Despins, Farahbakhsh & Leidl, 2009; Gikas & Tsihrintzis, 2012).

The lack of first flush demonstrates one of the drawbacks of the blanket approach adopted by the KDWSP – where they have shortcomings in project implementation, these will be replicated among all installations. Inadequate drainage was noted at 70% of the installations, leading to stagnant water that increases the likelihood of spreading waterborne disease by vectors. More frequent rainfall in the wet season washes away debris which provides an explanation for why more sites presented with contaminated roofs and dirty guttering during the dry season.

The cleanliness of the RWH systems was notably high on both visits, with low incidence of (9) dirty cement floor and (5) pollution around tank. This could be attributed to the quality of the capacity building carried out by the KDWSP, but there is also likelihood that, knowing sites would be involved in the assessment, site managers and homeowners cleaned installations prior to the researcher's visit.

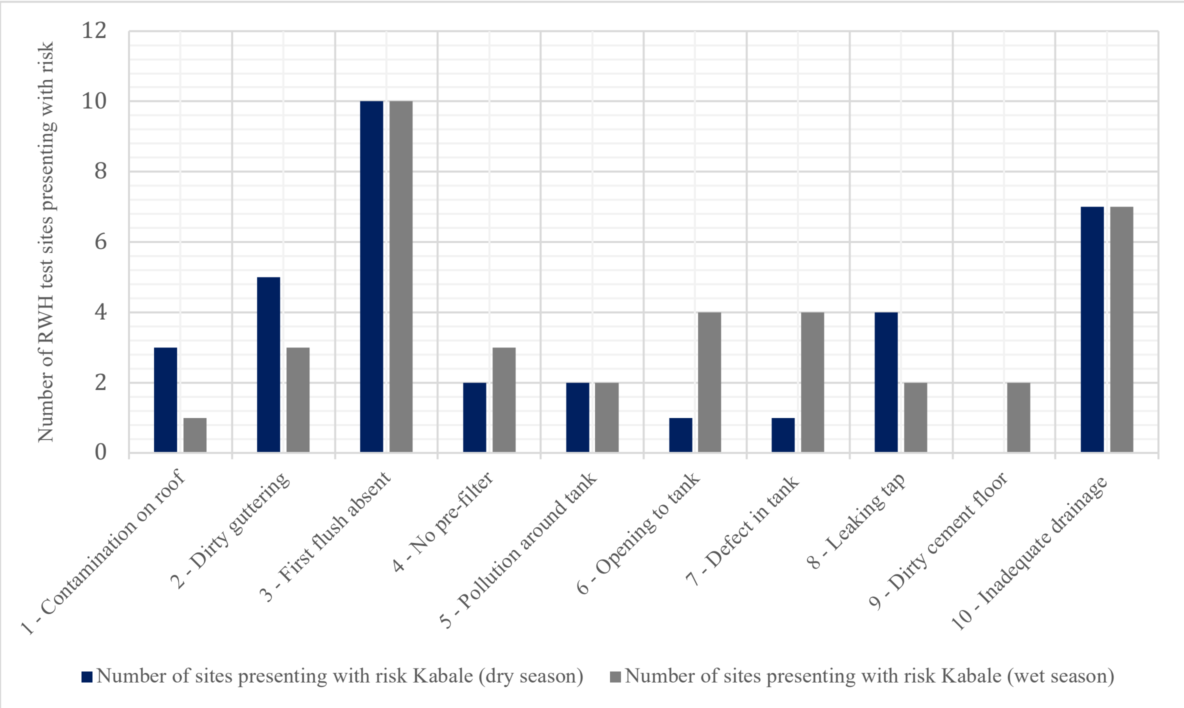


Figure 21 - Sanitary Survey results for the ten RWH sites in the Kabale case study (dry and wet season)

Homeowners with RWH systems who had been trained by the KDWSP felt well-equipped to maintain their systems and the sanitary survey results confirm that these systems were well-maintained. The sanitary survey results for the institutional sites also demonstrated good maintenance practices. Nonetheless, many community members reiterated similar sentiment that '*management of the system at home is easier because you take full responsibility for it' (Focus group participant)*.

6.2.9 Mitigate Risk of Conflict

Conflict in communities over water access can arise at various degrees of severity. Less severe (and a common challenge associated with community water provisioning) is resentment among community members when certain households are selected for water access, while others are not. More severe conflict can arise when disagreements occur over the management and pricing of water services. At the most significant end of the scale is physical violence that occurs due to power clashes over access to water, and violent or sexual attacks on women while travelling long distances alone to fetch water.

The focus groups' discussions provided a forum to explore points of conflict associated with community water access. Participants identified '*long queues'* at community tap stands as a source of frustration for water users, but no conflict over control of water was mentioned. There seemed to be good acceptance of the selection process that the KDWSP used to choose RWH sites. This can likely be attributed to the KDWSP's strong roots in the community, and the clear communication they adopt when discussing site selection. However, it must be noted that focus group participants may have felt the need to provide positive feedback about the KDWSP's approach, given the role of the KDWSP in facilitating the interviews.

No focus group participant described feelings of resentment over families that were provided with a subsidised RWH system. It appears that this was not a significant point of conflict, though further research would be needed to confirm this. It may be that these findings were limited by participants' willingness to discuss conflict in an open forum.

Figure 22 - Focus group discussion held in July 2019 in Kabale with a male translator from the community (middle left)

Participants described points of conflict over the management of water between husband and wife. Women felt that it was unjust that the responsibility to manage water lay solely with them. '*Risks to personal security*' was the most notable theme to arise from the topic of conflict surrounding water access in Kabale. Both women and children were identified as community members who were vulnerable to attack when collecting water from distant sources.

Women spoke of fear of '*rape, attack, and stealing young girls*' when accessing water from the river. The fear of attack meant that women and girls fetched water during daylight hours, or during the morning when they perceived the journey to be safer. One drawback of this was that the morning was viewed as '*productive*' time and fetching water in morning hours reduced the amount of time women had to carry out agricultural, entrepreneurial or domestic endeavours. '*Avoiding attack*' was cited as a significant driver for on-site RWH. Women felt that the presence of domestic RWH significantly reduced the likelihood that they, or their children, would be attacked while collecting water.

6.2.10 Support Livelihoods

Livelihood generation was a core theme generated from the end-user interviews and focus group discussions. Two sub-themes that developed were livelihood generation through agricultural activities, and income-generating activities through water-based entrepreneurial activities. Kabale is a highly agricultural district. 74.2% of households in Kabale grow crops, and 30.2% have livestock. Agriculture is the main occupation of the population with 82% producing at subsistence level and the rest on a semi–commercial basis (Langan & Farmer, 2014). This trend was prevalent in the community group:

> *'What we do for income mainly, and also for food security, is growing Irish potatoes, then sorghum, and beans. The potatoes are the main source of income and also the source of food security'(KI02a).*

The importance of farming for livelihoods provides an explanation for why climate irregularities that impact the annual growth of crops have such a disruptive effect on quality of life within the community. When asked what focus group participants used their water for, as many participants selected '*agriculture*' as '*cooking and cleaning'*.

Large-scale irrigation is a challenge for a community that does not have access to a centralised water network. Rainwater harvesting provides the only opportunity for community members to irrigate on-site crops (used for both household consumption and for sale). The dry season (or '*drought'*, as called by interviewees) was viewed as more detrimental to crop growth than the wet season. Three end-users involved in pastoral farming reported cows dying due to a lack of grass and feed, which could not be provided without water. One end-user reported the destruction of banana plantations due to an overflowing tank, highlighting the importance of sizing the tank correctly for the catchment area.

Water was deemed essential for a range of activities associated with productivity. The most frequently mentioned job roles were *'crop and livestock farming, charcoal burning, working in the quarry and construction' (Focus group participants)*. On-site water access was associated with '*improved production time'* as women no longer had to travel long distances to fetch water. Focus group participants explained they used this time for '*preparing seed beds for vegetables and also for spraying different crops',* which increased their income. Selling water was also a form of income, and several of the end-users sold water for concrete production and plastering in local construction projects.

As the KDWSP do not construct tanks, but rather train end-users to construct tanks themselves, this upskilling means end-users are left with a marketable skill at the end of the process. Initially, the KDWSP's skilled staff spend a month in the community running end-user workshops. End-users are trained in a group and construct five to ten systems together as a team. The KDWSP then supervise the construction of ten more tanks per user until they are satisfied that end-users are appropriately skilled to independently install RWH systems. End-users then, effectively become sole traders, and begin constructing new tanks for customers for a fee. This process is referred to as '*self-supply' (KI02b)* and is seen as both beneficial to the community and cost effective to the KDWSP, as they do not have to pay the fees for highly skilled labourers.

End-users spoke of a '*sense of purpose' (EU07)* associated with their new skills, because they could proactively seek out new customers. This was viewed as appealing because they were gaining '*more than just the RWH system' (EU07)* from the process. The findings from the end-user interviews suggest that one of the most significant drivers of RWH adoption in Kabale was the ability for end-users to generate their own income through the combined benefits of improved crop yield due to more reliable water access, and the skill-building associated with RWH construction.

6.3 RWH and Water Security Goals in Kabale

By answering research sub-question (2), several of the outcomes of RWH use in the Kabale community have been identified. The radar chart presented in Figure 23 represents a subjective assessment of where RWH best meets the goals of water security in Kabale, and where further progress is needed. Overall, for the RWH systems assessed in Kabale, RWH is effectively managed, and strongly supports livelihoods. The quality of water is acceptable by WHO standards and the right mechanisms are in place for the systems to be sustained over their design life. The presence of the systems reduces the likelihood of conflict, in particular attacks on women while collecting water from afar.

The systems are affordable to most users and can be accessed equitably to a degree. Nevertheless, price and access for the poorest members of the community are still a challenge. Where RWH does not meet the goals associated with water security is in year-round availability of water. For all users, a supplementary water source was required for at least 100 days a year. This number could be reduced with larger water storage and with training on water conservation practices.

Key for Radar Diagram:

0 – Fails to meet this goal

1 – Significant weakness in meeting this goal

2 – Weakness in meeting this goal

3 – Meets this goal somewhat

4 – Provides a significant contribution to this goal

5 – Meets this goal well

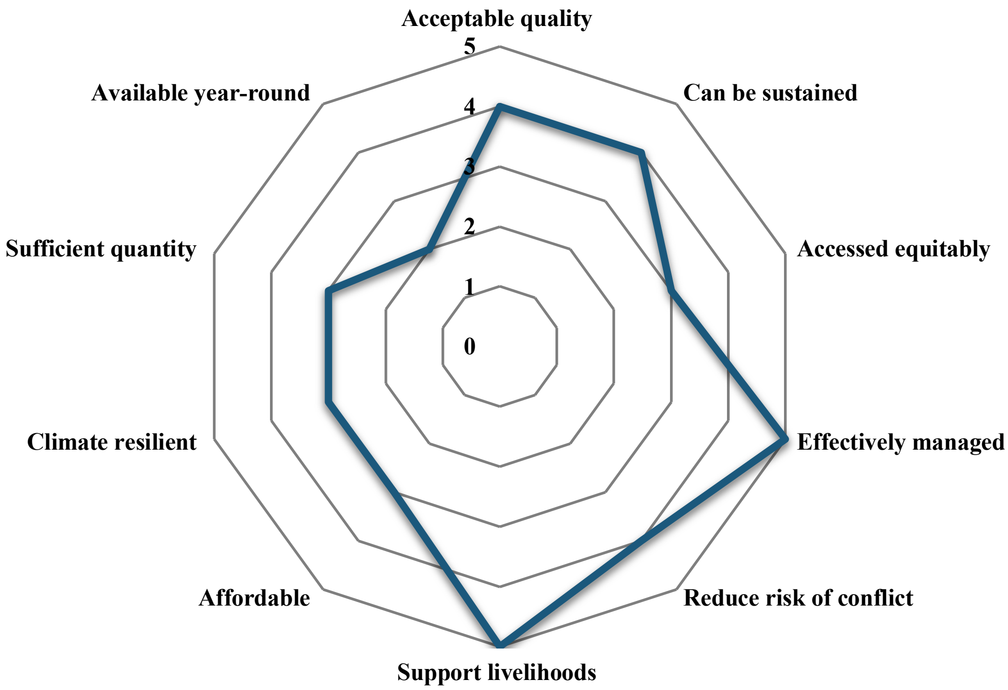


Figure 23 - Radar chart demonstrating the strengths and weaknesses of RWH delivered by the KDWSP in Kabale when assessed by water security goals

6.4 Drivers of the Adoption of Rainwater Harvesting in Kabale

The application of the water security framework developed in Chapter 4 to a sample of ten rainwater harvesting sites in the community provided answers to elements of the main research question: *'what are the sociotechnical drivers, barriers and outcomes of rainwater harvesting use in communities in Uganda?'* Both drivers and barriers to the adoption of RWH were identified through the analysis, the most significant of which are presented below.

The most significant drivers of RWH adoption were:

1. **Proximity of water.** The community reported having faced climate challenges for over a decade. From 2009, extreme flooding caused hundreds of households to relocate from the bottom of the valley to further up the hillside to avoid the impact of landslides. It was during this period of time that the KDWSP began the widespread implementation of RWH systems in order to provide community members with either household water access or access within 100 metres of the majority of homes. This relocation was one of the primary drivers of the widespread adoption of RWH, as on-site water access was desperately needed once the distance to the primary water source (river) greatly increased. This meant women and children in particular spent less time fetching water or queueing for water, were less vulnerable to attack while travelling to collect water and had more time to carry out productive tasks such a domestic chores and income-generating activities.

2. Access to a greater volume of water on-site had a positive impact on **livelihood generation** as community members had water to carry out agricultural activities, where produce was sold for a profit. Additionally, **the 'self-supply' model**, where end-users are trained on the construction and maintenance of RWH systems, enabled end-users to generate income from reaching new RWH customers, effectively creating a microenterprise for end-users.

3. **Protection against climate unpredictability.** Despite the reliance of RWH on rainfall, the storage included in RWH systems allows end-users to better control their water access. This means, with planning, households have a 'buffer' of water storage for times of lengthy (or unexpected) dry periods.

4. **Support from local institution.** The presence of the KDWSP improved the community's awareness of RWH, and the community's ability to afford and sustain their RWH systems. The two sites that did not have the support of the KDWSP in the construction and maintenance of the RWH systems exhibited poor upkeep and water quality. While this may have been due to the age of the RWH systems, the

evidence suggests that the KDWSP's presence improves the likelihood of adoption of RWH in the community.

5. For women, **avoiding attack** while out fetching water from long distances was highlighted as a significant incentive to adopt on-site RWH. Water access close to home meant that women did not need to travel long distances by foot to access water. The women among the community explained that this was a time where they felt most vulnerable to violent attack.

The most significant drivers of the sustained upkeep of RWH systems were:

1. The **ease and affordability** of upkeep of RWH systems.
2. The **capacity-building and training approach** adopted by the KDWSP, resulting in end-users feeling well-equipped to maintain RWH systems.
3. **Engagement with both male and female** household members to both contribute to the upkeep of RWH systems.

Despite the strong correlation between well-maintained systems and good water quality, sustaining good water quality was not identified as a driver to maintain and sustain RWH systems.

6.5 Barriers to the Adoption of Rainwater Harvesting in Kabale

The assessment identified the following barriers to the adoption of RWH in the community:

1. **The high capital cost of RWH systems.** Although the KDWSP provided heavy subsidies for the poorest members of the community, focus group participants did not feel that RWH systems were affordable for the poorest community members. Systems installed on institutions provided community access to water for free, but these systems suffered from similar drawbacks to existing water services: time-consuming queues and journeys to-and-from water points.

2. Availability of water from RWH is significantly **limited by annual fluctuations in rainfall**. These can be mitigated by water-conservation practices, but the small storage tank size found in the case study creates a barrier to year-round supply. Future climate models predict that rainfall in the region will become less evenly distributed throughout the year, exacerbating the issue.

6.6 Limitations in Findings

There are some limitations to the findings in this case study. For example, data was collected at only two points in time and so the information provided was solely as a 'snapshot' of events. It is likely that the researcher's presence had an impact on the focus groups and end-users' responses. As participants were aware that they would be involved in a study, their care of RWH systems was probably greater than what it would have been on a normal day, influencing the site assessment results.

As the researcher was reliant on the KDWSP to select participants, it is possible that the KDWSP selected the 'best' RWH systems, which would also have skewed the results. That said, several of the key informants who were selected for interview were interviewed without the involvement of the KDWSP to ensure independent voices.

In Kabale, the Ministry of Water and Environment estimates that only 1908 people or 1% of the population are served by RWH (MWE, 2019). In this region, the KDWSP are the most prominent implementer of RWH, having installed over 800 tanks since the mid-1990s, suggesting that many of the RWH users in the region have been installed in line with the KDWSP approach (Danert & Motts, 2009b). For the other users in the community, the self-constructed mortar-jar assessed at Household sites E and F is likely to be typical. However, a limitation of the small sample size is that undoubtedly some types of RWH user within the community were not represented in this study.

The use of the water security framework led to certain limitations. For example, given the semi-structured nature of the focus group discussions and key informant interviews, participants in the study provided more information on certain goals compared to others (e.g., much more information was collected on ‘livelihoods’ than on ‘risk of conflict’). This provided the researcher with a more comprehensive picture of some of the water security goals over others.

While the structure of the framework allowed for a detailed understanding of certain water security goals, it also restricted discussion on the human relationship with water in other ways. One unique example is that of water and health. Good hygiene and sanitation were noted as a significant benefit of on-site water access by several end-users. Due to the structure of the framework, the researcher’s ability to focus on hygiene as a component of water security was limited.

‘*Stress and anxiety’* were highlighted by community members as a significant burden associated with poor water access, but ‘improving mental health’ was not identified through the literature review or the practitioner interviews as a characteristic of water security. Discussion on the implications of these limitations will be presented in Chapter 8.

7 URBAN COMMUNITY CASE STUDY

This is the second of the 'two-case' case study chapters, where the findings from the application of the water security framework to the assessment of RWH sites in Mbarara, the urban case study community, are presented. The findings provide answers to research sub-question (2) '*to what extent have specific rainwater harvesting interventions met sociotechnical water security goals in Ugandan communities?'*.

Household and institutional RWH sites from the community were assessed individually against each of the ten water security goals of the framework. The assessments were then combined to provide an overall indication of the extent to which rainwater harvesting has met water security goals in Mbarara. Through the process of applying the water security framework to the rainwater harvesting sample sites the drivers, barriers and outcomes of rainwater harvesting use in Mbarara were identified, providing answers to the main research question.

7.1 Rainwater Harvesting Sample Sites

The rainwater harvesting sites involved in this study were located in the Kakoba division of Mbarara municipality, the urban centre of the municipality, with an approximate population of 62,670 (MWE, 2020a). The ten sample sites were selected from fourteen sites visited by the researcher, at each site RWH was used as a *supplementary* water provisioning service in addition to piped water.

No formal community RWH initiative could be found in Kakoba. Instead, residents and institutions that had access to RWH alongside piped water were contacted through links with RWH installers from the Mbarara Plumber's Association. Four institutional RWH sites and six domestic sites were involved in the study. Table 16 provides further detail on the RWH site assessments.

7.1.1 Institutional Sites

The four institutional sites selected for the study included a convent with 20 full-time residents and a rainwater harvesting system with an HDPE tank funded by church partners, a primary school with a very large (360m^3 tank volume) ferrocement system, an adult learning centre and a hospital serving approximately 500 patients. None of the institutional sites reported providing water to the wider community, indicating an absence of a communal approach to water management in the urban case study. Figure 24 shows the technical drawing for the design of the ferrocement tank at the Development Studies Centre. Ferrocement tanks were reported to be preferable to HDPE alternatives due to their strength and ease of repair.

Prices for RWH systems are comparable to Kabale: a 5000-litre HDPE tank costs 1,500,000 UGX (£318), just for the tank. A 20,000 litre HDPE tanks costs 6,696,325 UGX (£1417). A 40,000 litre ferrocement tank and system installation costs 10,000,000 UGX (£2,116) at an exchange rate of 4725 UGX: £1.

Site Name	Site Description	# of users	Institutional/ Household	Tank Type	Roof Area (m2)	Tank Volume (m3)	Vol of water consumed/ day (m3)	Year of Installation	Price of RWH System (UGX)
Convent	Institution with 20 full time residents. Well-funded by church. Well maintained RWH with 4 tanks and 4 roofs using RWH. Candle filter used for water treatment.	20	Institutional	HDPE	250	68	0.4	2017	30,000,000
Primary School	Primary school with both municipal and RWH. Reports that the 180,000 litre tank overflows when rains are heavy.	150	Institutional	Ferrocement	750	360	3	2014	80,000,000
Development Studies Centre	Adult learning centre with 10 full time residents, up to 30 students during high season. Well-maintained. UV filtration for treatment.	25	Institutional	Ferrocement	150	40	0.5	2018	13,000,000
Hospital	Hospital with RWH and chlorine dosing mechanisms. Tank constructed by an NGO with donations from the local brewery.	500	Institutional	Ferrocement	900	180	10	2008	40,000,000
Household Site G	High income household. 5 members. Well-maintained tanks. Small arable farm on site.	5	Household	HDPE	200	10	0.1	2013	5,000,000
Household Site H	4-member household. Very large tank for roof size. Newly constructed.	4	Household	Ferrocement	150	18	0.08	2018	6,000,000
Household Site I	3-member household. Well-constructed and maintained tank.	3	Household	Ferrocement	150	10	0.06	2016	5,000,000
Household Site J	Household with 5 family members. Well-constructed and maintained tank.	5	Household	HDPE	75	5	0.1	2012	3,000,000
Household Site K	Household with 4 members and small chicken farm. Small roof and tank.	4	Household	HDPE	40	4	0.08	2016	2,000,000
Household Site L	Very large household with ties to the church. Up to 35 people living there at any one time.	35	Household	Ferrocement	120	40	0.7	2014	13,000,000

Table 16 - Technical summary of RWH installations included in the Mbarara case study

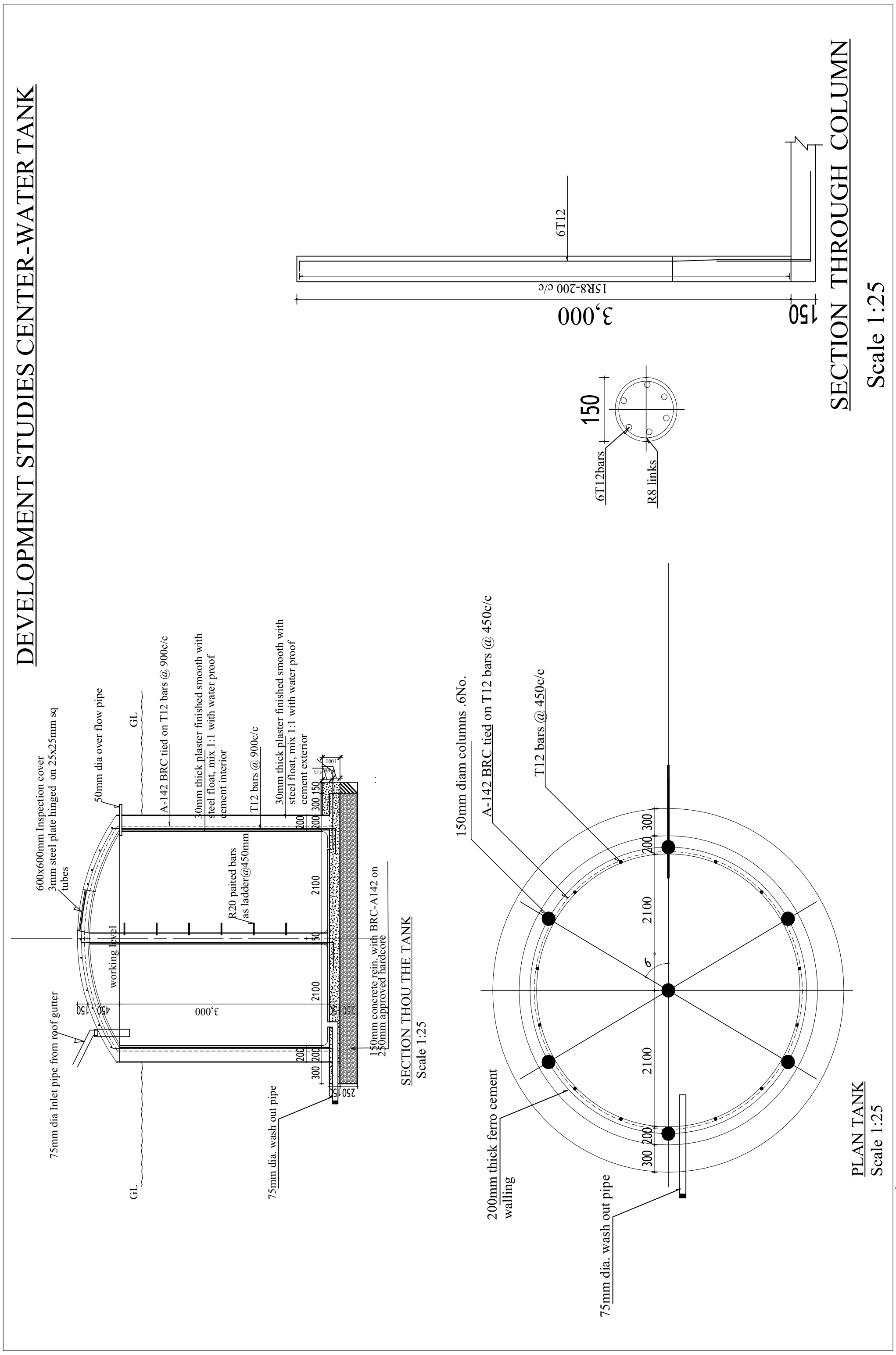


Figure 24 - Rainwater harvesting ferrocement tank design for the Development Studies Centre in Mbarara. Source: Mbarara Plumbers Association.

7.1.2 Household Sites

In order to better understand how RWH meets the water security goals of populations already served by an onsite water source, and to be representative of the municipality's demographics, sites were selected based on the following criteria:

- RWH was an additional water source on top of piped water or an on-site borehole.
- All end-users were principally employed in the commercial, business or education sector (rather than agriculture).
- All RWH tanks were privately funded by end-users themselves.
- Prior to adopting RWH tanks, users believed they had suffered from water insecurity.

The household sites were all located in the Kakoba division of Mbarara municipality. Sites G and K had small farms (arable and pastoral respectively) located on site. Sites G-K had between three and five household members. Site L was a large household that engaged in foster care, and so at times had up to 35 people living there.

7.2 RWH and Community Water Security Goals

As with Kabale, the results from the assessments of the RWH sites against the ten water security goals are presented. Detailed information is provided on how the RWH interventions in Mbarara have met each of the water security goals, and the final results are summarised towards the end of the chapter.

7.2.1 Acceptable Water Quality for Good Health

Bacteriological and physio-chemical tests were carried out on samples from each of the ten RWH systems and at the point of use of the municipal water supply at each site. In addition, end-user interviews provided information on the users' perception of water quality. End-users were asked to provide a ranking of 1 (terrible) – 5 (excellent) on the taste and smell of water from their RWH system. End-users were also asked about frequency of the most common symptoms associated with waterborne disease - vomiting and diarrhoea.

Of the six household sites, four of the respondents ranked the taste and smell of water from RWH at 4 (good) and two at 5 (excellent). The taste and smell of the water at the institutional sites was ranked at 5 (excellent) at the convent, 3 (OK) in the school, and 4 (good) at the adult learning centre and hospital. Overall, this indicates a positive perception of the water quality.

The WHO's guidelines on drinking water quality classify thermotolerant coliforms (TTCs) into four risk categories: 1. no risk (<1 CFU/100ml), 2. low risk (1-10CFU/100ml), 3. medium risk (>10-100CFU/100ml), and 4. high risk (>100 CFU/100ml) and state that TTC count per 100ml should be zero (WHO, 2008).

30% of sites tested positive for TTCs in the WHO medium risk category: 10-100 CFU/100ml (Table 17). At all sites where TTCs were identified, the water had a turbidity above 5 NTU, and so failed to meet both TTC and turbidity standards (WHO, 2008). The turbidity across the sample selection was high, with only three sites meeting WHO standards in both the dry and wet season. All sites that tested positive for TTCs in the 2018 visit (wet), did so also in the 2019 visit (dry). The pH recorded at all of the test sites lay in the WHO's acceptable range of 6.5 - 8.5.

Site Name	pH Median (n=2)		Turbidity (NTU) Median (n=2)		CFU/100ml Mean* (range) (n=4)	
	Dry season	**Wet Season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**
Convent	6.8	6.9	5	10	<1	<1
Primary School	8.2	8.2	20	20	23.2 (12 – 50)	9.9 (6 - 20)
Development Studies Centre	6.8	6.8	0	0	<1	<1
Hospital	6.8	7	10	20	<1	<1
Household Site G	8.2	8.1	0	0	<1	<1
Household Site H	8.2	8	20	20	21.6 (12 – 40)	17.1 (8 – 30)
Household Site I	6.8	6.8	10	20	<1	<1
Household Site J	6.9	6.8	20	0	<1	<1
Household Site K	7	7	10	15	53.5 (36 – 70)	29.1 (15 - 50)
Household Site L	7.2	7.2	0	0	<1	<1

Table 17 - Physiochemical and bacteriological test results for RWH samples from institutional and domestic sites in Mbarara, Uganda (n=10). *Geometric mean

Overall, 70% of the sites failed to meet the WHO standards for turbidity. This may be because catchment areas for urban RWH systems are vulnerable to localised pollutants from traffic and construction debris, which can impact the turbidity of water.

The municipal water supply was also subject to bacteriological and physiochemical tests. End-users in Mbarara cited *'poor water quality of municipal water' (EU15)* as a key driver of RWH adoption. Nonetheless, presence of TTCs was not detected from the municipal tap at any of the sites. Turbidity, however, failed to adhere to WHO guidelines at 80% of the sites. This may provide some explanation for the end-users' mistrust of quality, as visual indicators of poor water quality such as haziness have a strong influence on perception of quality.

Site Name	pH Median (n=2)		Turbidity (NTU) Median (n=2)		CFU/100ml Mean* (range) (n=4)	
	Dry season	Wet Season	Dry season	Wet season	Dry season	Wet season
Convent	6.8	6.9	0	0	<1	<1
Primary School	7	7	0	10	<1	<1
Development Studies Centre	6.8	7	0	10	<1	<1
Hospital	6.8	7	20	10	<1	<1
Household Site G	6.5	6.8	5	5	<1	<1
Household Site H	7	7	20	20	<1	<1
Household Site I	6.8	6.8	5	5	<1	<1
Household Site J	6.8	6.8	20	20	<1	<1
Household Site K	7	7	20	20	<1	<1
Household Site L	7	7	0	0	<1	<1

Table 18 - Physiochemical and bacteriological test results for tap water samples from institutional and domestic sites in Mbarara, Uganda (n=10). *Geometric mean

All users reported treating both rainwater and municipal water before drinking. Five of the domestic end-users reported using boiling as their primary treatment method for both RWH and municipal supply. Two users reported that rust in the municipal water was a driver of adopting RWH, with one user stating: '*when we boil municipal water, it becomes brown, this is why we prefer to drink rainwater' (EU18).* The other domestic user purchased a 20-litre water bottle refill each month for 5000 UGX (£1.06). The hospital, convent and Development Studies Centre all had a UV filtration system in place at a cost of approximately 1,417,500 UGX (£300), while at the primary school, boiling was the primary form of treatment.

7.2.2 Available Year-Round

Figure 25 shows the results from the water balance models for the institutions in Mbarara. For the 2018/2019 simulation period, no significant rainfall occurred until October, and so RWH tanks remained empty for the July-September period. In order to represent the worst-case scenario, the simulation is based on the assumption that all RWH tanks are empty at the beginning of the simulation. This may not have been the case in reality.

Additionally, the simulation is based on the assumption that all users are supplied with 20 litres per day from the RWH system, however, end-users all reported on-site access to municipal water in addition to RWH. With this in mind, the water balance model provides an estimate of the 'worst-case scenario' for the year-round availability of water from RWH.

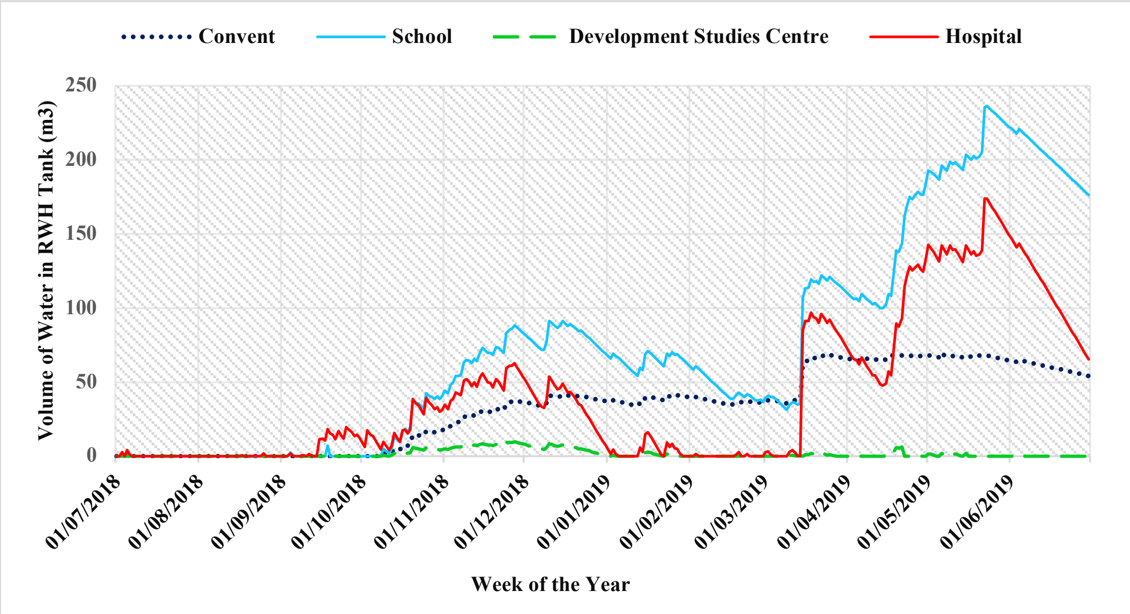


Figure 25 - Results from water balance simulation estimating volume of water in RWH tanks at four institutional sites in Mbarara between July 2018 and June 2019

Estimates of availability of water from RWH mirrored seasonal variability in rainfall, with adequate supply for three out of the four institutions in the wetter periods of October-December and April-May. Significant rainfall in the April-May period meant that, given the large size of RWH tanks at the institutions, a 'buffer' of water supply carried forward into June 2019. The smallest of the institutions (by RWH tank size and number of users served), the Development Studies Centre, was more vulnerable to rainfall fluctuations. Table 19 indicates that the RWH tank at the Development Studies Centre was empty for 227 days compared to approximately 100 days per annum for the other institutional sites. This suggests that the RWH tank was sized too small for the water demand of the site.

Site Name	# of days a year empty	# of days a year of overflow
Convent	98	19
School	95	0
Development Studies Centre	227	0
Hospital	108	0

Table 19 - Results from RWH balance model indicating empty days & overflow days for Mbarara institutional sites

The household sites, in contrast, were empty for fewer days in the year, but five out of six sites suffered from a significant number of days of overflow (mean=43, n=6). The household sites that suffered from overflow all had RWH tank sizes < $18m^3$ with 3-5 members of the household consuming water. Household site L, which had 35 inhabitants and a RWH tank volume of $40m^3$ did not suffer from overflow but because of the significant water demand, the tank was empty for 233 days of the year.

Site Number	# of days a year empty	# of days a year of overflow
Site G	3	56
Site H	87	45
Site I	49	58
Site J	36	60
Site K	49	40
Site L	233	0

Table 20 - Results from RWH balance model indicating days empty & overflow days for Mbarara household sites

In Figure 26, the water balance model results for household sites G-K suggest that the RWH tanks are too small for the catchment size to maximise the potential water capture of the RWH systems. Figure 26 shows that at each of these sites, overflow occurs on numerous days. Household sites would benefit from larger RWH tanks in order to maximise water savings. Key informant interviews with the mason and plumbers suggest that tank size is limited by the price that end-users are willing to pay. Additionally, KI03a indicated that the size of the catchment area did not influence the size of the tank, i.e., for larger catchments, tank size was not increased.

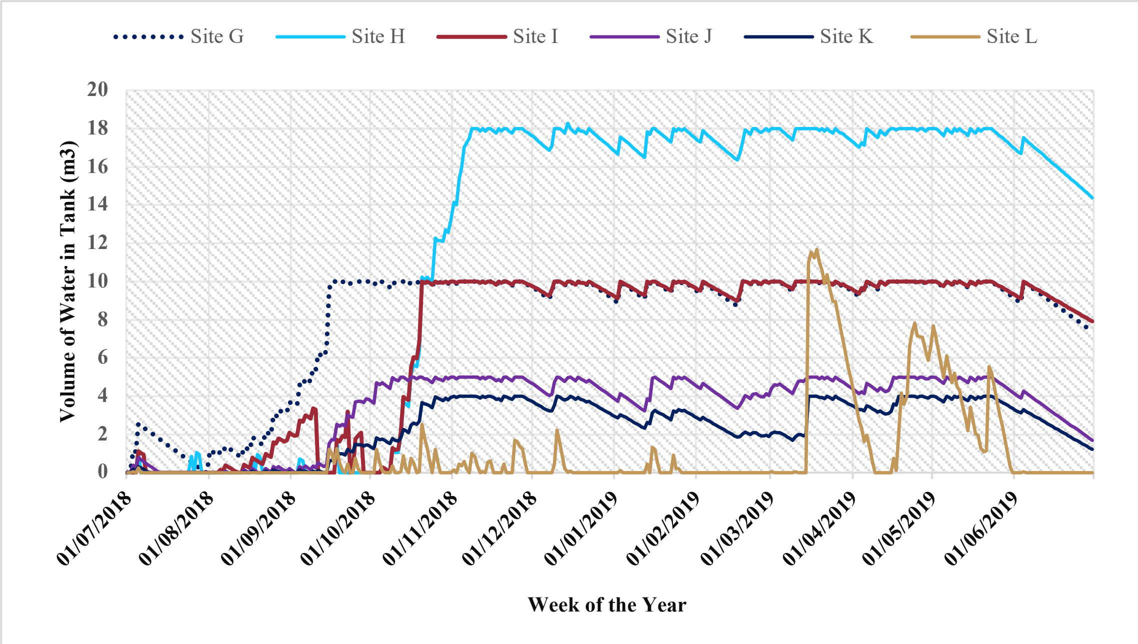


Figure 26 - Results from water balance simulation estimating volume of water in RWH tanks at six household sites in Mbarara between July 2018 and June 2019

Overall, the water balance models indicate that RWH systems alone cannot satisfy the water demand at either the institutional or domestic sites. Only one of the institutional sites suffered from issues of overflowing, indicating that the other tanks were sized correctly for the estimated supplementary demand of users and the catchment size. Nonetheless, as a result of the high water demand, institutional sites could not meet the user demand for a mean of 132 days a year (n=4).

End-users felt that, knowing that RWH is dependent on annual rainfall fluctuations, it was acceptable for RWH tanks to be empty for a portion of the year. At all ten sites in Mbarara, the primary water source was the municipal water supply provided by NWSC. In response to the question 'do you have access to water all year round?', all ten end-users responded 'yes'. At all sites, the RWH system was used as a secondary water source, and on the days when it was empty, the household resorted to using municipal water:

> *'When we use the tanks depends on the weather, when we have much rain then we use the rainwater, and when it is dry season, of course the tanks get dry, and we use national water' (EU11).*

Predictably, during the dry season, end-users felt more water stressed. This stress arose from higher water bills, because water usage could not be supplemented by RWH during these drier months (the availability of municipal water did not vary based on seasonality).

The nature of the rainfall profile in Mbarara is short and intense periods of rainfall, which can exacerbate the challenge of overflow. End-users described overflow as a central challenge to RWH tank management:

> *'In one season it takes only two weeks to fill those tanks. When we have a lot of rain like in November or maybe in March, two weeks the tanks are full, so as we have nowhere to put the water, we let it overflow' (EU19).*

Correct sizing of RWH tanks for catchment area, along with management of water demand through conservation practices could enable improved water security by reducing the number of days domestic and institutional tanks overflow or are empty.

7.2.3 Sufficient Quantity

Overall, accessing sufficient quantity of water was not deemed to be a challenge by end-users. While '*interruptions in municipal supply' (EU13)* were cited as a driver for the adoption of RWH, when users described their overall water access, most explained they had 'enough' water for day-to-day activities.

'*Cooking, bathing and cleaning' (EU15, EU17, EU18, EU19)* were cited at all domestic sites as critical activities that required water. Two of the domestic sites (G & K) carried out agricultural activities that required water usage. End-users at both these sites felt that municipal water was too costly to be used for crops and livestock. As a result, their key driver for adopting RWH was to reduce water bills and to continue on-site agricultural activities to generate household revenue. It must be noted that at both these sites, agricultural activities were *secondary* sources of income, both end-users had full time jobs, at Site G in engineering and at Site K in banking.

The end-user at Site K explains why he decided to adopt RWH:

> *'This area we are in is one of the highest. Most other areas are lower than this. There are times when the municipal water pressure is not strong enough to reach us, and so my municipal tank does not fill. I can go two, three, days without National Water. In this case, I need another source, and RWH meets this need for me. I am never absent of water anymore' (EU19).*

At all domestic sites, the combination of municipal water and RWH was enough for end-users to report they did not suffer from water stress. End-users described practising conservation techniques to sustain rainwater through the dry season and expressed frustration at the frequency with which tanks overflowed. At the institutional sites, meeting the demand of students or residents was seen as a challenge, as water-conservation practices were difficult to engrain in user populations. As a result, institutional end-users at the hospital, convent and Development Studies Centre felt that they would benefit from additional tanks within their premises to capture water from site rooftops that weren't yet being used for RWH. The barrier to this expansion was cited as '*funding*' at all three sites.

7.2.4 Climate Resilient

End-users expressed concern about both flooding and drought. Both household and institutional users described periods of intense rainfall in April that caused localised flooding. Intensity of rainfall was also identified as detrimental to infrastructure, with *'inadequate drainage'* cited by focus group members as a cause of flooding in urban areas. End-users at the Development Studies Centre and the hospital believed that domestic and institutional RWH reduced the risk of flooding by capturing rainfall that would have otherwise been diverted as surface water.

Drought was not stated as a significant issue by end-users. Additionally, focus group respondents did not view drought to be a driver of service interruptions to municipal water. Instead, participants believed service interruptions to be caused by *'poor management from NWSC' (Focus group participant).*

End-users were asked about the unpredictability of weather patterns. '*Change in the timing of rainfall*' *(EU14)* was identified as a cause of disruption to the local economy:

> *'I'm not an expert but I know normally, we receive rain at the end of February, but now the rains come in May and they disappear in June and then come back in the beginning of July. This year, you see, a kilo of beans is at 3000 UGX. It used to be at 700 UGX when there is a lot of harvest. So, you can see that there is a lot of change, a lot of change as far as the rains are concerned' (EU14).*

Focus group participants explained that in recent years, in response to shifts in the timing of rainfall, different crops had appeared in the local market. There had been a concerted effort to adapt the types of crops grown to those that were more resilient to short intense rainfall and longer periods of drought such as '*pineapple, mango and yam' (EU13)*. This proactive approach to climate adaptation meant that vendors could still turn a profit when traditional crops could not grow in newly developed rainfall patterns. For household G which had a small, arable farm, the end-user explained that without the RWH system, he would not grow crops because of the high cost of irrigation with national water.

The RWH systems themselves were seen as particularly vulnerable to climate fluctuations. End-users cited frustrations with the frequency with which overflow occurred. This was attributed to the frequency of very intense rainfall events. At sites J and K, where overflow occurred on 60 and 40 days of the year respectively, end-users stated that cost and lack of awareness of alternative options were the reasons why they had relatively small RWH tanks (5m^3 and 4m^3 respectively). At these sites, both end-users had engaged a private contractor from Mbarara Plumbers' Association to install a RWH system. The contractor provided a quote for a RWH system with the tank size pre-confirmed, and end-users did not feel well-equipped to challenge the sizing, given a lack of knowledge on appropriate tank size for catchments.

Overall, as the community was not reliant on rain-fed agriculture for income, their vulnerability to climate disruption was low. There was evidence that the community had adapted to new rainfall patterns by growing crops that were better suited to short, intense rainfall and could survive prolonged drought. At certain sites, in particular the household sites with smaller tanks, RWH systems could not cope with high rainfall levels.

7.2.5 Affordable

High cost of municipal water was cited as a driver of RWH adoption by all six domestic end-users, several focus group participants and by 75% of institutional site managers. The end-user at Site K explains:

> *'The national water is not reliable. It can be off for three days. It is also expensive, especially for anyone wanting to do irrigation. You can still be water stressed when there is water, but you can't afford it' (EU19).*

It was not, however, the absolute cost of municipal water that was the principal cause of user dissatisfaction. Instead, a sense that municipal water did not provide value for money drove users to seek alternative water supply. End-users reported dissatisfaction with a 'service charge' of 1500 UGX (£0.31) per month. Although the charge was small, end-users felt that the service they received was inadequate, citing '*poor water quality'*, '*service interruptions'* and '*rust colour' (EU17)* as characteristics of the water supply that were unacceptable. There was significant mistrust of the pricing of the municipal water, with end-users and focus group participants unconvinced that the service provided good value for money:

> *'The National Water say they have to expand into smaller towns which don't have any water. The cost of those projects has to be paid by National Water. The contracts to lay pipes, new water works, etc are quite expensive. National Water say they don't get money from the government, so they have to increase our bill to pay for this expansion' (Focus group participant).*

Municipal water in Mbarara is priced at 3516 UGX/m^3 (£0.74/m^3). A family of five people, each using 20 litres/person/day can expect a monthly bill of 10,548 UGX (£2.23). However, water bills from the household sites for July 2019 report a much higher water usage per person per day (as can be seen in Table 21). This is to be expected, as the WHO estimates of 20 litres/person/day are a *minimum* requirement. Sites G and K both conducted on-site agricultural activities, leading to high water consumption at both sites.

Site #	**Price per m³ (UGX)**	**Volume of water used (m³)**	**Cost of water (UGX)**	**Service Charge (UGX)**	**VAT @ 18% (UGX)**	**Total Monthly Spend (UGX)**	**Total Monthly Spend (GBP)**
Site G	3516	25	87900	1500	15822	105,222	22.27
Site H	3516	5	17580	1500	3164	22,244	4.71
Site I	3516	12	42192	1500	7595	51,287	10.85
Site J	3516	10	35160	1500	6329	42,989	9.10
Site K	3516	15	52740	1500	9493	63,733	13.49
Site L	3516	40	140640	1500	25315	16,7455	35.44

Table 21 - Monthly spend on municipal water for Mbarara domestic sites. Source: household water bill, July 2019

It is assumed that during the month of July, the water demand is serviced entirely by municipal water as July is one of the driest months in the year, and so harvested rainwater is minimal. As a result, the above municipal water bills are likely to be the maximum amount end-users would spend on monthly piped water services. All of the water for domestic sites was likely to have been provided by municipal services in this period.

In comparison, the costs of RWH are presented in Table 22. The mean annual cost of maintenance at the institutions was 283,806 UGX (£60) and 100,500 UGX (£21) for households. End-users reported contacting the same contractor that installed the RWH system to carry out maintenance or repairs. *'Once or twice a year' (EU17, EU19)* was cited as the frequency with which maintenance or repairs on systems were needed.

The high cost of maintenance in Mbarara can be attributed to repairs and maintenance being carried out by contractors rather than homeowners themselves. At only 20% of sites did end-users report carrying out maintenance activities, and all sites reported '*contacting installer' (EU15)* as the action they would take if the RWH system was not working.

Site #	Tank Size	Tank Type	Cost of RWH System (UGX)	Cost of RWH System (GBP)	Annual Cost of Maintenance (UGX)	Annual Cost of Maintenance (GBP)
Convent	68	HDPE	30,000,000	6,349	250000	53
Primary School	360	Ferrocement	80,000,000	16,931	365000	77
Development Studies Centre	40	Ferrocement	13,000,000	2,751	95000	20
Hospital	180	Ferrocement	40,000,000	8,466	425225	90
Household Site G	10	HDPE	5,000,000	1,058	106000	22
Household Site H	18	Ferrocement	6,000,000	1,270	88000	19
Household Site I	10	Ferrocement	5,000,000	1,058	85000	18
Household Site J	5	HDPE	3,000,000	635	84000	18
Household Site K	4	HDPE	2,000,000	423	115000	24
Household Site L	40	Ferrocement	13,000,000	2,751	125000	26

Table 22 - Costs of RWH system at 10 assessment sites in Mbarara

End-users described the cost of municipal water as '*expensive*' *(EU18)* but, in contrast, viewed RWH as '*a good investment*' *(EU18)* and so did not feel deterred by the high capital cost. There was a good understanding of the savings that could be made on the water bill by investing in RWH. However, the view that municipal water was expensive appears to be based on dissatisfaction with service rather than on absolute cost.

Taking for example, site J. Over a 10-year period, the cumulative spend on a RWH system is £815. The annual water bill for site J can be approximated at £109.20 (assuming the same monthly usage each month as occurred in July 2019, so this would be a maximum value). Over a 10-year period, the water bill will be approximately £1092 (assuming no increase in tariff). This is higher than a 10-year spend on RWH. However, the water balance models have demonstrated that RWH cannot meet the entire annual household demand, whereas municipal water could. RWH systems can reduce household water bills by reducing the demand for municipal water. Nevertheless, as a result of poor year-round availability, they cannot replace municipal supply entirely.

End-users stated that they would rather invest in a RWH system over which they had total control than pay for a service that they did not trust. In addition, end-users had a clear view of what municipal water should be used for, and where RWH provided a better water source. For the two domestic sites that carried out on-site agricultural activities, both noted that their municipal water bill increased dramatically when carrying out irrigation:

> *'I have tried municipal water for irrigation for my tomato garden, but the bill doubles. Now, if you consider me paying 10,000 UGX (£2.12) extra for irrigating my tomato garden during the dry season, I'm better off using this money to buy tomatoes. So, for people who are going to do irrigation, you cannot do irrigation with the national water. It's too expensive' (EU15).*

All ten end-users (both institutional and domestic) paid upfront the full price of the RWH system. No users mentioned any type of microfinancing scheme or loans initiative. When asked about funding, at five of the six household sites, end-users funded the RWH systems privately from *'savings'*. At site L, due to the nature of the activities that took place at the site (foster care), a portion of the funding for the RWH system was provided by a local church to support these activities. Despite the high capital cost for end-users, they felt that the RWH systems were good value because they significantly reduced the municipal water spend. In contrast, those focus group participants who did not have access to RWH explained that '*high capital cost'* was a significant deterrent to adoption of RWH.

7.2.6 Can be Sustained

As with the Kabale case study, a Likert scale was presented to end-users with the question 'On a scale of 1-5, how confident do you feel in maintaining your system?' 1 (not confident at all), 2 (under confident), 3 (fairly confident), 4 (very confident), 5 (extremely confident). Confidence among the end-users in Mbarara was low, with 60% of end-users reporting they '*did not feel confident at all in maintaining their RWH systems'*. This does not necessarily mean that RWH units were poorly maintained, but it does indicate that no training, capacity-building or self-supply approach was in place.

At the hospital and household site L, end-users felt confident in their ability to maintain systems and cited activities such as '*cleaning roofs, leaves, debris, and the inside of tanks' (EU14, EU20)* as activities they carried out themselves. At the hospital site, the confidence in maintaining the system stemmed from the presence of an on-site team dedicated to the maintenance of the hospital grounds.

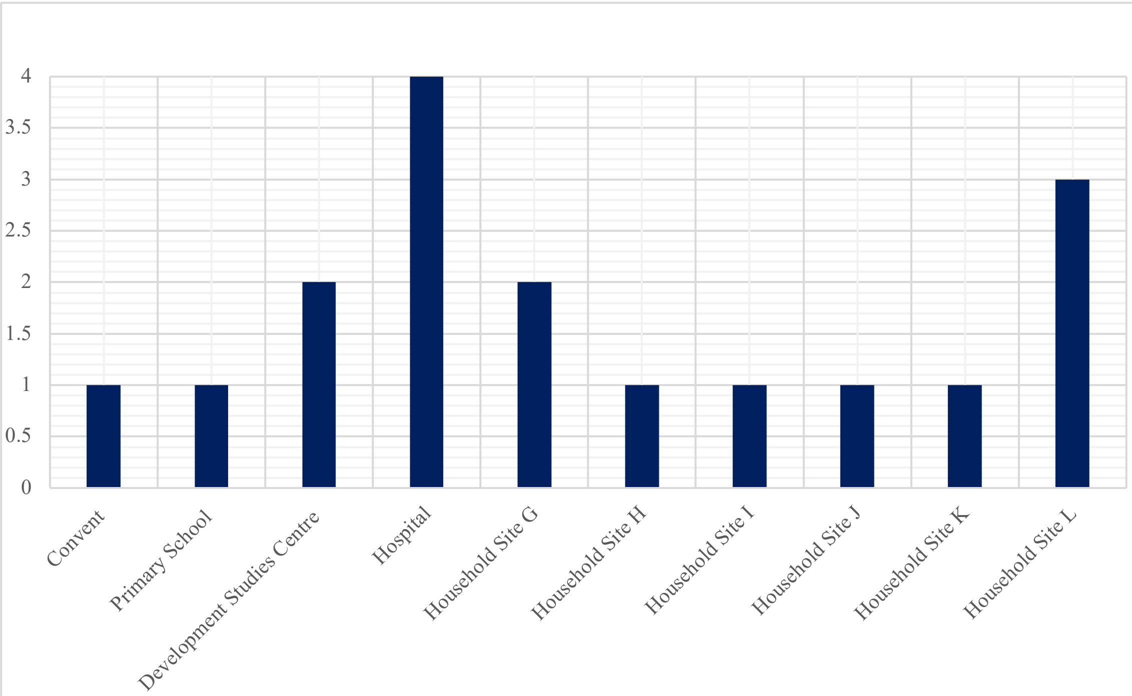


Figure 27 - Likert Scale responses (1 to 5) for ten RWH assessment sites in Mbarara. On a scale of 1 to 5, how confident do you feel in maintaining your RWH system?

When asked about nature and frequency of repairs, no single end-user reported repairing RWH systems themselves. Required repairs included '*changing filters and guttering and repairing cracks in tanks' (EU17, EU19).* As every RWH system had been installed by a private contractor, end-users explained that they would contact this contractor in the eventuality of a system failure. At 80% of sites, the plumber from the Mbarara Plumber's Association who installed the system would return to carry out checks on the system:

> *'The plumber comes once a year. The same organisation comes once a year and does the maintenance and then if they have to change the piece, you pay for that piece, maybe 230,000 UGX (£49)' (EU17).*

The RWH systems were all built between 2012 and 2018, with a design life of 20-30 years (if well maintained). 40% of the sites had HDPE tanks, which are advertised with a similar design life. However, at both the convent and household Site G, where HDPE tanks were in place, users reported previous tank failure where cracking had occurred. In both these cases, end-users stated that the entire tank needed to be replaced. This was cited as a significant deterrent to the use of HDPE tanks. Overall, the under-confidence of end-users in maintaining systems themselves reflects a lack of training on RWH usage and management.

7.2.7 Accessed Equitably

Whether participants in the focus groups had access to RWH was principally dictated by ability to afford the high capital cost of a RWH system. At all of the institutional sites in Mbarara water was used only by the people for whom the sites were designed to serve (e.g., patients in the hospital, children at the school). As a result, the equitable access of water from RWH systems within the community was poor. Overwhelmingly, ability to pay for the service was the deciding factor in the adoption of RWH systems.

For those members of the focus groups that did not have on-site RWH, lack of awareness of the technology was another barrier to adoption. Participants stated that they did not know RWH was an option, and several members of the group had a vague understanding of the technology but did not know how to source or finance formalised RWH. This may help to explain why RWH appears to be underutilised in this part of Uganda.

A water supply engineer with specialism in RWH explained that, within the Kakoba division of Mbarara, he did not know of any specific programmes to encourage community RWH or to engage with the local community. As Mbarara municipality is supplied by municipal water, water insecure populations within that geographic region were not supported to access alternative water sources, as it was believed they could gain access to municipal water if needed.

> *'It would be good to have a community water harvesting project around the community, or if they don't have roofs, we collect from another reservoir and make sure that this water supplies the community. For me, if you're thinking about any project, we should have some form of demonstration in an institutional area, but also it should extend to the community. Right now, there is no organisation to coordinate this type of project. No funding for it' (KI04).*

In Mbarara, equitable access to water services is highly reliant on access to the centralised water network and ability to pay for these water services. Those stakeholders that fall out of this group, represented by several members of the focus groups, explained that there are no initiatives to support their water access. In a 2017 study, Lukubye & Andama estimated that only 47.5% of the population of Mbarara municipality had access to municipal water. However, on the Ministry of Water and Environment's (MWE) Water Supply Atlas, an online database that publishes national water access statistics, the number of urban users without access to municipal water is not a documented user-group.

An interviewee from the NWSC explained that the current strategic goal of the NWSC is to connect more populations to the municipal water supply, and so funding is directed towards expanding the municipal network, rather than supporting populations who cannot afford, or are not satisfied with the municipal water.

7.2.8 Effectively Managed with the Support of Institutions

From the question 'On a scale of 1-5, how confident do you feel in maintaining your system?' it was identified that end-users did not feel equipped to maintain their RWH systems themselves. No formal training or capacity building was carried out with end-users. Maintenance was outsourced to the plumber, or organisation that installed the RWH system, and end-users paid a fee for required maintenance. This service did not cover regular cleaning of systems, which is required to reduce the risk that water from RWH becomes contaminated.

Sanitary surveys provided a good indication of the state of RWH systems and the cleaning and maintenance activities that had been carried out by end-users. The risk of contamination score (ROC) provides an overall indication of how likely it is that water from RWH is contaminated based on the state of the RWH system. A score closer to 10 corresponds to more hazards present during the survey. The results of the sanitary surveys are presented in Table 23.

Site Name	Site Description	ROC Score, Dry Season (max 10)	ROC Score, Wet Season (max 10)
Convent	Institution with 20 full time residents. Well-funded by church. Well maintained system with fuel pump and 4 tanks and 4 roofs using RWH. Candle filter used for water treatment.	2	2
Primary School	Primary school with both municipal and RWH. Reports that 180,000 litre storage overflows when rains are heavy.	7	7
Development Studies Centre	Adult learning centre with 10 full time residents, up to 30 students during high season. Well-maintained. UV filtration for treatment.	2	2
Hospital	Hospital with RWH and chlorine dosing mechanisms. Tank constructed by an NGO with donations from the local brewery.	3	3
Household Site G	High income household. 5 members. Well-maintained tanks. Small arable farm on site.	2	2
Household Site H	4-member household. Very large tank for roof size. Newly constructed.	6	7
Household Site I	3-member household. Well-constructed and maintained tank.	3	4
Household Site J	Household with 5 family members. Well-constructed and maintained tank.	3	4
Household Site K	Household with 4 members and small chicken farm. Small roof and tank.	6	7
Household Site L	Very large household with ties to the church. Up to 35 people living there at any one time as home is used as a foster care site.	4	4

Table 23 - Risk of Contamination (ROC) scores for RWH institutional and household sites in Mbarara (n=10)

There was a strong correlation between sites presenting with high ROC scores and those that did not adhere to WHO water quality guidelines. The primary school and sites H and K all presented with thermotolerant coliforms, and at each of these sites, ROC scores were above 6 out of 10. This suggests there is a strong correlation between maintenance and cleaning practices and water quality. The remainder of the sites had low ROC scores, with the seven other sites scoring less than 4 out of 10 in both the dry and wet seasons. The low ROC scores indicate that the RWH systems have been well maintained. Despite 60% of end-users reporting that they did not feel confident in maintaining their systems themselves, 80% of end-users responded that the RWH systems were cleaned 'about once a month'. At household sites G, I, J and L, end-users reported that they had a member of staff employed to maintain their house who frequently cleaned RWH systems including roofs, pipes and guttering.

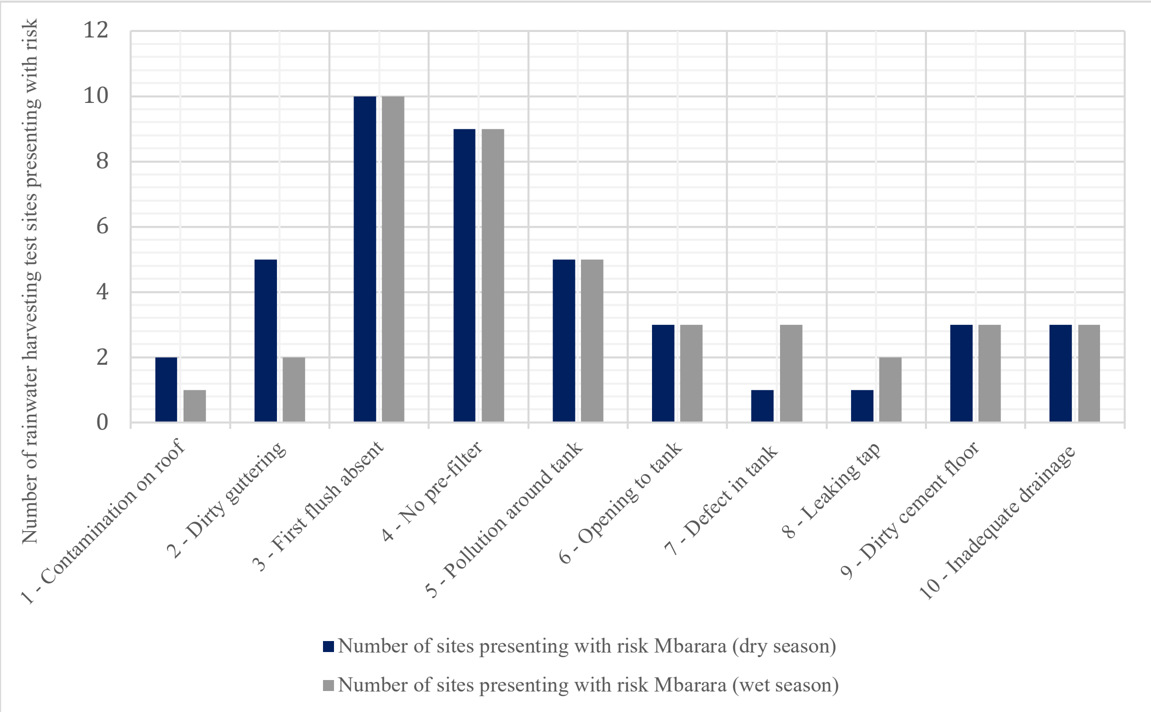


Figure 28 - Sanitary Survey results for the ten RWH sites in the Mbarara case study (dry and wet season)

Figure 28 shows the number of sites in Mbarara presenting with each risk identified in the sanitary survey. The most common risks across the test sites were a lack of first flush (dry=10, wet=10, n=10), lack of pre-filter (dry=9, wet=9, n=10), pollution around tank (dry=5, wet=5, n=10) and dirty guttering (dry=5, wet=2 n=10). Both a first-flush and pre-filter are simple mechanisms that can significantly reduce the risk of contamination. A first flush was absent at all of the sites and only at one site was a pre-filter present.

Overall, the sanitary surveys indicate that the RWH systems involved in the study were effectively managed and maintained. Nonetheless, there was a notable lack of institutional support provided for end-users. There was no evidence of any support on RWH system maintenance and management from the National Water and Sewerage Corporation, the Ministry of Water and Environment, or any other organisation. That is not to say it may not exist in Mbarara, but end-users, interviewees and focus group participants all stated that no institutional support was available for community members who were seeking RWH.

There was conviction among end-users that ownership and responsibility for RWH systems were the sole responsibility of end-users themselves. As a result, they felt they needed to take a proactive role in ensuring RWH systems functioned correctly. In the absence of formal training, the indicators and cues used to assess 'correct functioning' of a RWH system by end-users were limited to '*leaking and dirty water' (EU16)*.

A notable drawback of the lack of a formalised training programme was that skills and knowledge were restricted to the implementing organisation (Mbarara Plumbers' Association), and therefore not distributed among the community. Local plumbers explained that they trained other plumbers within the group to carry out the masonry work required for RWH tank construction but did not ever train members of the community as there was no need, incentive or will to do so.

7.2.9 Mitigate Risk of Conflict

In response to the questions 'does conflict ever exist in your community over water access? If so, who is involved? Which actors are in charge of diffusing conflict? Over which points are there disagreement in the community regarding water access?' (See Appendix III for further questions), participants identified illegal water use as the most significant source of conflict within the community. Illegal water tapping is a common occurrence in low-resource settings. Typically, illegal consumers either draw water from the piped network, reverse water meters or intentionally tamper with the water meter so that it counts backwards to the desired reading (UN-Habitat, 2012b).

The conflict associated with illegal water tapping originated from a sense of injustice that some members of the community paid for water and others did not. The NWSC has also identified illegal water tapping as a significant barrier to sustainable water supply. In 2020, a notice was released by the NWSC stating:

> *'It is for a fact that access to water is a human right, but that does not mean it is a limitless right and that access to water should be uncontrolled and free' (NWSC, 2020).*

Overall, conflict over water access was not deemed to be a significant issue within the community. The exception to this was when the illegal water tap was located beyond the household water meter, and so, in effect the perpetrator was stealing from the customer rather than the NWSC. Focus group members explained that the normal course of action would be to confront the perpetrators, and if the theft did not abate, they would be reported to the NWSC. In this way, the NWSC acts as an institution that provides structure and monitors water usage, but the deep mistrust of the NWSC among the focus group participants undermined its ability to effectively govern water access. There was no evidence that the RWH systems assessed in this case study mitigated risk of conflict within the community.

7.2.10 Support Livelihoods

According to the Uganda Bureau of Statistics, only 25.4% of households in Mbarara municipality rely on farming as a main source of livelihood. In contrast, 89.9% of households have at least one member who is engaged in non-agricultural employment or enterprise (UBOS, 2014). Unlike in Kabale, livelihoods are not dominated by rainfed agriculture. As a result, livelihoods and household incomes are less dependent on reliable water supply.

At household sites G and K, where end-users engaged in on-site farming, the RWH systems were critical for end-users to carry out pastoral and arable farming. The municipal water bills for July 2019 at site G and K in July 2019 were 105,222 UGX (£22.27) and 63,733 UGX (£13.49) respectively. At both sites, end-users stated that the maximum monthly water bill they felt comfortable with was 25,000 UGX (£5.29). Above this fee, the extra cost of water associated with irrigation rendered on-site agricultural activities unprofitable. Despite the high capital cost associated with RWH, these end-users felt comfortable spending on RWH, as they believed that in the long run they were saving money on water bills.

At the convent, primary school and Development Studies Centre, interviewees stated that, prior to the installation of the RWH units, they could not afford their water bills. As a result, municipal water supply was often switched off. At sites with more than twenty users, where water access was not easily controlled, end-users explained that RWH was essential to supply enough water to stakeholders and students and that the RWH system had significantly reduced their municipal water bills, improving cashflow for the organisations. At the convent, this in turn '*reduced anxiety and stress*' *(EU11)* for the nuns that took care of the property.

At only one site did entrepreneurial activities associated with the selling of water take place. At household Site L, the end-user bottled water from the RWH system and sold this bottled water for a profit. He explained that he saw an opportunity to make a profit from selling the excess water from his RWH system. As with the agricultural sites, this activity was not the user's primary source of income.

The market for RWH systems in Mbarara generated activity for local plumbers and masons. Interviewees from the Mbarara Plumbers' Association stated that RWH jobs generated profits for their small businesses. In order to meet demand, local plumbers took on apprentices and trained them in RWH system construction.

7.3 RWH and Water Security Goals in Mbarara

By answering research sub-question (2), several of the outcomes of RWH use in the Mbarara community have been identified. Despite access to municipal water supply, end-users in Mbarara still felt that they suffered from water insecurity due to poor municipal water quality, interruptions in service, and, for some users, inability to afford monthly water bills. As a result, the end-users involved in the study had chosen to invest in on-site RWH.

For the sample group in Mbarara, RWH provided good water quality for 70% of the sites assessed. Water quality could be improved with better management and maintenance of RWH systems, which requires institutional support and community training. Both were noticeably absent in this case study. It was estimated that water from RWH systems would not have been available year-round, but all sites did have year-round access to water through the combination of RWH and municipal water supply. End-users described rarely running short of water due to their combined water access, but in the driest month of July, most of the water needs were serviced by municipal water rather than RWH. Water conservation practices from RWH were not commonplace.

RWH systems were vulnerable to both drought and extreme rainfall, the latter causing overflow at several sites. This overflow could have been minimised by increasing the size of RWH tanks. As the community in question did not rely heavily on subsistence farming, they did not view themselves as vulnerable to climate shocks. High capital cost was a deterrent for community members who had not yet adopted RWH, but end-users who had, felt that RWH offered better value for money than municipal supply. There was no evidence to suggest that the presence of RWH within the community mitigated the risk of conflict over water services, which arose from illegal water tapping of the municipal supply.

At none of the institutional sites was water shared with the general public, and given the high capital costs associated with RWH, low-income community members did not feel they could readily access RWH services. Site assessments indicated that systems were well constructed and could be sustained for a 20 to 30-year lifespan. Despite 80% of end-users feeling under-confident in maintaining their RWH systems themselves, at these sites, the private plumbers who had installed the systems carried out regular annual maintenance for a fee. The radar chart presented in Figure 29 demonstrates where RWH best meets the goals of water security in Mbarara, and where further progress is needed. Key:

0 – Fails to meet this goal

1 – Significant weakness in meeting this goal

2 – Weakness in meeting this goal

3 – Meets this goal somewhat

4 – Provides a significant contribution to this goal

5 – Meets this goal well

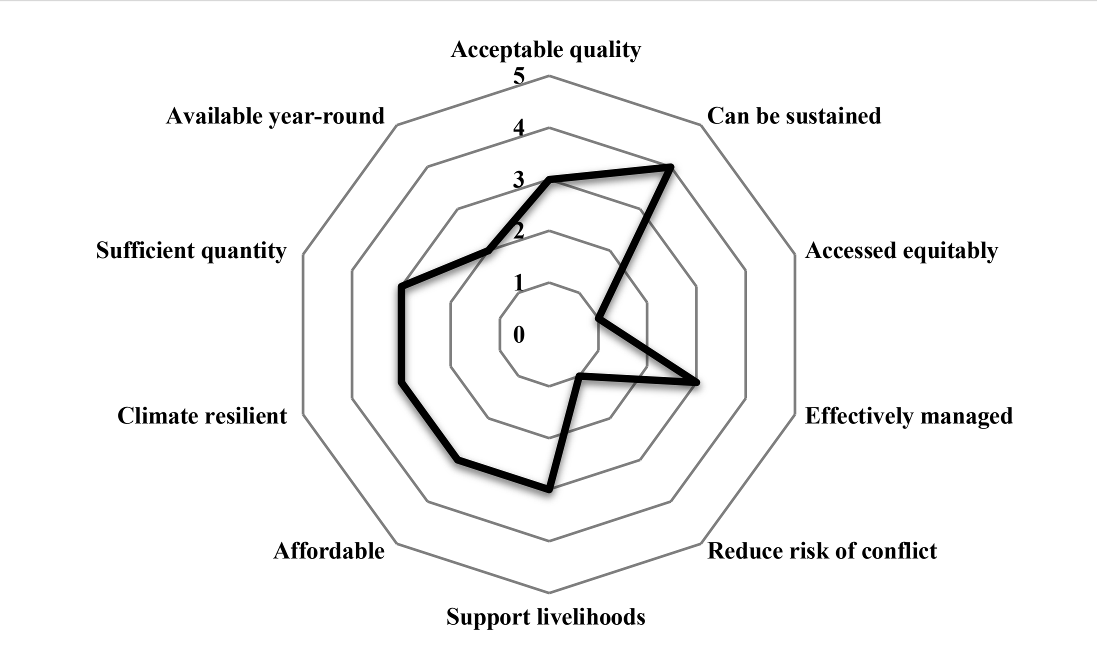


Figure 29 - Radar chart demonstrating the strengths and weaknesses of RWH in Mbarara when assessed by water security goals

7.4 Drivers of the Adoption of Rainwater Harvesting in Mbarara

The application of the water security framework developed in Chapter 4 to a sample of ten rainwater harvesting sites in the urban community provided answers to elements of the main research question: *'what are the sociotechnical drivers, barriers and outcomes of rainwater harvesting use in communities in Uganda?'* Both drivers and barriers to the adoption of RWH were identified through the analysis, the most significant of which are presented below.

The most significant drivers of RWH adoption were:

1. **Poor water quality from municipal water supply.** The water quality tests revealed that turbidity of the municipal water did not meet WHO standards. End-users cited a 'rust colour' in the water as indication that it was not fit for consumption. This drove users to acquire alternative water sources.

2. **Interruptions in municipal supply** undermined trust in the centralised water system. Users sought RWH to supplement their water needs throughout the year.

3. **Reduction in water bills.** A poor sense of value for money for municipal supply was a significant driver for RWH use. Despite comparable costs for municipal water and RWH over a 10-year period, end-users felt that on-site RWH was an investment that gave them control of their water supply. End-users preferred to 'invest' in their own water supply rather than to pay fixed fees.

4. There was **mistrust of the pricing of water bills**, as users did not feel that the municipal service provided good value. This was a key driver for users to seek ownership and control of their own water supply.

5. Two of the ten end-users had small on-site farms. At both sites end-users stated that **rainwater was critical for irrigation**. Without RWH systems, and due to the high

cost of municipal water, they would choose to purchase produce in the market rather than to manage their own crops and livestock.

7.5 Barriers to the Adoption of Rainwater Harvesting in Mbarara

The assessment identified the following barriers to the adoption of RWH in the community:

1. **Lack of available funding and finance mechanisms.** There was no evidence of institutional financial support for decentralised water services. All end-users either funded RWH systems from personal savings or from a specific partner donor, such as the church. Several members of the focus groups who had not adopted RWH explained that the **high capital cost** was a significant barrier to adoption.

2. **Lack of awareness of RWH.** Despite Uganda's biannual rainy seasons which well suit RWH, it is not a well-adopted technology in Mbarara municipality. Focus group members explained that they were not aware of it as a water-provisioning option. This lack of awareness may have been caused by a lack of institutional support for RWH.

3. The Ministry of Water and Environment in Uganda have made a concerted effort to connect all users to centralised water networks. As a result, funding for **decentralised water access is not an institutional** priority and so activities to design and build RWH systems are principally undertaken by private contractors, who do not have the reach of governmental departments.

The most significant barriers to the sustained upkeep of RWH systems were:

1. **Inadequate tank sizing** for catchment area and water demand, which led to significant overflow at the household sites. In contrast, each of the institutional sites suffered from a significant number of days per year that the tank was empty.

Availability of water from RWH could have been better managed with training on water conservation practices.

2. **A lack of institutional support or community training** in system management and maintenance. End-users did not feel confident in maintaining their systems, and with 30% of sites presenting with high ‘risk of contamination’ scores and poor water quality, there appears to be need for training in system maintenance and management.

7.6 Limitations in Findings

Limitations include the fact that the sample size was notably small and so is unlikely to be representative of the population that has adopted rainwater harvesting in Mbarara. The researcher relied on contacts through Afrinspire and the Mbarara Plumbers’ Association to reach end-users, and so the RWH systems analysed may have been in better condition than those of a random sample of the community, as the researcher may have been shown the ‘best examples’ of RWH sites.

In order to understand if conditions differed substantially between the dry season and the rainy season, information was collected at two points in time and so provided only a ‘snapshot’ of events. The accuracy of the RWH system assessment could be improved if continual monitoring over the year-long period could be guaranteed. This was, however, unfeasible within the boundaries of the research project. Only end-users that had access to municipal water supply were included in the study in order to understand their motivations for adopting RWH. Residents who had adopted RWH due to an absence of piped water supply were not included in the study, as one of the aims of this research was to identify the motivations behind adopting RWH when piped water was already available.

The use of the water security framework may have restricted discussion on the outcomes of RWH access. The application of the framework allowed for detailed information to be collected on the water security goals included in the framework, however other outcomes of RWH access may have been overlooked.

8 DISCUSSION

In this section, reflections on the strengths and weaknesses of the water security framework as a research and assessment tool are presented. Revisiting the research questions, this chapter will focus on answering sub-question (3) *'How do the drivers and barriers of RWH use differ between urban and rural communities in Uganda?'* and will provide answers to the main research question. Notable differences between the two communities are highlighted. Comparisons are made between the findings from each community and findings from the academic studies assessed in the literature review. Finally, the potential implications of the findings are discussed.

8.1 Reflections on the Water Security Framework

The framework was designed in response to calls for new contributions to the water security literature to focus on assessing water security at a community scale. The framework provided a structure to enable data collection in the field, useful for researchers, WASH NGOs, water service providers and governmental water organisations.

Scholars have previously had reservations about the 'indicator' approach reducing water security to a set of numbers (Jepson *et al.*, 2017). Solely using indicators to assess water security does not allow for the complexity and causality between water security characteristics to be readily identified or understood. Indicators are a good tool to measure and communicate the components that make up water security definitions, but they do not provide a structure to assess progress towards water security goals. In order to overcome this, the framework was designed not purely to quantify water security, but also to define and describe water security through the use of goals and metrics, some of which were quantifiable, and others which required qualitative descriptors. The structure of the framework encourages researchers to collect a range of qualitative and quantitative data.

The benefit of providing a tool for *assessment* rather than *measurement* is that it allows for the complexity and nuance of water security to be captured and ensures meeting water security goals is not reduced to simply 'a tick-box' exercise.

One of the core benefits of the framework approach was that it provided a holistic picture of each community's relationship with water. The goals allowed for assessment of what is deemed important in the human relationship with water, and the framework provided a wider narrative of what water-provisioning programmes should be trying to accomplish.

Jepson *et al.* (2017) assert that the incentive behind framings of water security is to move away from purely the materiality of water access in itself. The framework developed in this study allowed the researcher to assess community water supply in a holistic manner, emphasising the second-order benefits of water access. This provided a method to demonstrate just how critical good water service delivery is to achieving not just Sustainable Development Goal 6, but all of the SDGs.

Previous work by Bitterman *et al.* (2016) aimed to develop a water security framework to measure water security in the context of rainwater harvesting. As with the tool developed by Bitterman *et al.* (2016), the framework allows for the causality between water security goals to be identified. Through the application of the framework to the case study assessment, it became clear that many of the water security goals were strongly dependent on each other. For example, the analysis demonstrated that the quality of water from RWH was linked to how well the RWH systems had been maintained. This, in turn, was reliant on training and capacity-building support from the KDWSP. Equitable access to RWH systems relied on the poorest members of the community accessing funding mechanisms and was improved by good management of community systems. There was strong evidence to suggest that RWH supported agricultural and microenterprise activities. However, these still relied on year-round availability of water, the lack of which is one of rainwater harvesting's greatest weaknesses.

The identification of the interrelations between each of the water security goals allows for stakeholders to understand how efforts to improve RWH implementation can be effectively directed, and which policies and mechanisms are likely to improve uptake of RWH across Uganda. For example, improving financing mechanisms to fund the high capital cost of RWH would improve the equitable access to water services among the community groups.

The rigid structure of the framework left no room for those components of water security excluded from the framework to be assessed. For example, from the stakeholder interviews, ‘protection of ecosystems’ was eliminated as a water security goal as it was not seen as a priority for the water practitioners who informed the design of the framework. Questions associated with ecosystems were not included in the end-user interview guide or in the focus group discussion. On reflection, this represents a drawback of the framework, as in the rural study, comments on the impacts of deforestation causing landslides, floods and deforestation were not explored in detail due to the restrictions of the framework design.

Focus group participants in Kabale discussed the relationship between poor water security and mental health challenges such as stress and anxiety caused by the uncertainty surrounding future water supply. The rigid structure of the framework did not allow for this relationship to be further explored.

As with other water security assessments that focused on a community scale, this framework focused more on anthropocentric factors than environmental factors. This reflects the nature of the research question, where answers on sociotechnical drivers, barriers and outcomes were sought. However, as Vörösmarty *et al.* (2018) found, threats to ecosystems certainly impact the human relationship with water. Further research to build upon the findings from this study should look to identify the relationship between environmental and sociotechnical outcomes of RWH use in rural and urban communities.

8.2 Case Study Comparison

The principle aim of the ‘two-case’ case study was to identify a wide range of environmental, institutional and socioeconomic factors that influence water security in contrasting community structures. The findings from the case study provided insight into how the challenges and opportunities associated with RWH differ between the urban and rural communities, as well as providing contrasting socioeconomic contexts in which to explore the utility of the framework.

The two cases exhibit certain typical characteristics of rural and urban water users in sub-Saharan Africa. The findings, therefore, may help to inform the delivery of RWH programmes for similar user groups in the region. There is still, globally, a marked disparity in water access between rural and urban populations. The majority of people who do not have access to safe drinking water live in rural settings. This is largely due to the absence of centralised water supply. The community in Kabale selected for this study reflected this condition, a low-income community with no access to centralised water supply (KDWSP, 2020). Despite suffering from economic water insecurity, the area is not water stressed. It has high levels of rainfall but disrupted climate patterns. In the rural case study, a formalised RWH 'programme' was in place, coordinated by a faith-based charity, the KDWSP. This is representative of the delivery of decentralised water services across rural sub-Saharan Africa, where, still today, charities and NGOs are the most significant actors involved in service delivery (Waterpreneurs, 2018).

The social boundaries of the urban community in the Kakoba division of Mbarara were much less clear than for the rural community. In the urban study, the sample group from the community was defined by geographic location, but social conditions that anchored the participants of the study to the 'community' were less evident than in Kabale.

As with the rural study group, the Mbarara community did not suffer from water stress. They had access to centralised water services and high annual rainfall levels. However, dissatisfaction with the price and service of the centralised water supply was a cause of water insecurity among the study group participants. This is representative of the conditions for millions of urban inhabitants across the world in emerging and low-income economies, where water infrastructure has not been able to meet the needs of rapidly expanding urban populations (UN-Water, 2018).

The significant drivers of RWH adoption and use in the rural community were proximity of water in comparison to alternative water sources, the potential for improved livelihoods, protection against climate unpredictability and support from the KDWSP. RWH provided the only on-site/household water access for the case study group. In contrast, the drivers for adoption among the urban case study community were poor municipal water quality, service interruptions and high costs associated with existing water services. This was compounded by poor sense of value for money and mistrust of the municipal service.

In Figure 30, these drivers are represented in a Venn Diagram. Where commonalities exist between the drivers in the two communities is in access to financing for RWH systems, support (or training) for RWH maintenance and upkeep, and in the opportunity to build resilience to unreliable and inconsistent water supply by diversifying water sources. While RWH itself suffers from inconsistency, diversifying water sources can ensure the number of days a year without on-site water supply can be minimised.

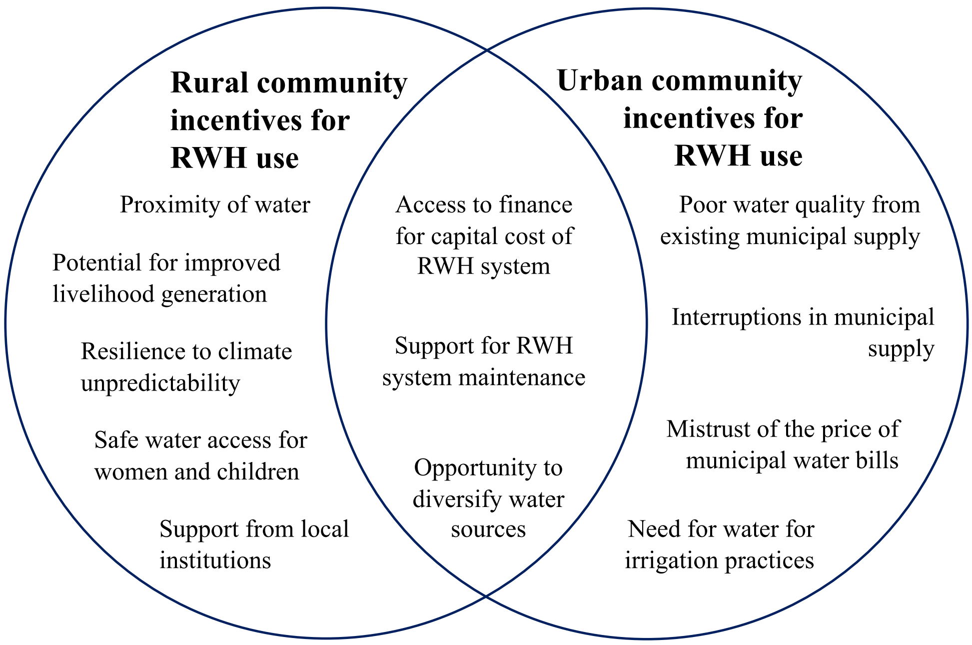


Figure 30 - Venn Diagram demonstrating drivers of RWH use in the urban and rural community

Further detail on the key differences in the drivers and barriers of RWH use between the urban and rural community is presented below. Findings from the case study are compared to findings from the literature review to identify commonalities and differences between this study and wider studies on water security and RWH.

8.2.1 Socioeconomic Conditions

While the climatic conditions were similar in the two communities, the socioeconomic conditions and the method of RWH implementation differed significantly. End-users in Mbarara were employed in business, education and trade rather than predominantly in agriculture, as in Kabale. In the rural community, a formalised RWH 'programme' was in place. In contrast, in the urban community, there was no institutional support for RWH.

The strongest impact of these differing socioeconomic conditions was on the drivers for the adoption of RWH. The end-user interview guide did not include questions about household income as the researcher was advised that this could have caused offence to interviewees, so information on economic status was derived from alternative questions such as end-users' ability to pay for RWH systems. In the urban cohort, end users paid for RWH systems upfront with no financial support, predominantly from 'savings'. This suggests a level of wealth higher than the rural cohort, all of whom received financial support for RWH from the KDWSP.

In the urban group, the financial incentive associated with the adoption of RWH was to reduce users' spend on municipal water services, which they deemed to be poor value. Among the rural group, the main financial incentive for RWH adoption was not to save money, but instead to improve users' potential to generate income through agricultural and entrepreneurial activities.

It was only among the rural cohort that access for the poorest users in the community – those that could not afford even subsidised domestic RWH installations – was facilitated. This was done by providing 'free' water to the community from institutional sites such as community churches. In the urban case study, where RWH installation was carried out by private plumbers, there was no evidence to suggest that the poorest users in Mbarara had access to RWH.

None of the end-users in the urban case study relied on rain-fed agriculture as a primary source of income. As a result, disruption of rainfall patterns did not have a significant impact on the cohort's productivity or income. In contrast, among the rural case study end-users, the presence of RWH significantly improved their ability to grow crops for consumption and sale. This was similar to findings by Kiggundu & Wanyama (2018) who found that in sub-Saharan Africa, RWH technologies can enable smallholder farmers, (such as those included in the rural site assessments) to be more resilient to increasing climate variability by conserving water and increasing food production, therefore improving food security.

It is not just when agricultural activities rely on close water access that RWH improves users' livelihoods. As Casey, Carter & Yeo (2012) found, the time and energy dedicated to fetching water affects people's ability to work, farm or attend school. Among the rural group, the proximity of water provided by RWH reduced the amount of time women and children spent collecting and managing water each day. This resulted in a reduction in risk of attack on women and an increase in the time available for women to carry out daily productive tasks.

Cross-culturally, women and girls tend to have greater responsibilities for household water acquisition and management practices (Jepson *et al.*, 2017). This means that achieving water security can free women from the burdens associated with these roles, giving them more time to pursue other activities such as educational or income-generating endeavours.

As with findings from Dismas, Mulungu & Mtalo (2018), high initial investment costs were cited in both case study groups as a barrier to the adoption of RWH. The high initial cost is principally down to the cost of tank construction. RWH is a long-term solution with a design life of 20-30 years. Despite the high capital cost, this study demonstrated that over a 20-year period, the overall costs of RWH are comparative to alternative water sources. The barrier to adoption for users, however, is not the price, it is access to funding. Financing schemes could open up this barrier to entry, but the question is who provides them? The financing mechanisms in place in the rural case study were a significant driver of RWH adoption and were critical in ensuring that RWH services were affordable to user groups.

As the NWSC focuses on connecting more people to the centralised network, funding is directed towards expanding the municipal network, rather than supporting populations who cannot afford, or are not satisfied with the municipal water. As a result, in Mbarara, there was a notable lack of institutional support for financing and maintaining RWH systems. Without financing to support the high initial costs, penetration rates will remain low across sub-Saharan Africa. Jepson *et al.* (2017) note that rainwater harvesting not only reduces the cost of centralised water bills but also enhances local expertise and provides a form of everyday autonomy from state power. For urban users, this was seen as desirable, where 'cost of water bills' and 'overcharging for services' was cited by several interviewees as drivers to adopt RWH.

8.2.2 Primary vs. Alternative Water Supply

A critical difference between the two user groups was access to municipal water supply. Referring back to the introduction, the consensus among researchers is that decentralised water services are appropriate to 'plug the gap' for communities such as Kabale, that do not have access to municipal water. Nonetheless, findings from the case studies demonstrate that, for users with piped water access, imperfect municipal services catalyse a desire for supplemented water access through RWH. In agreement with Pandey, Gupta & Anderson (2003) and Kahinda, Taigbenua & Borotob (2010), this suggests that RWH is not solely a water service that is beneficial in the absence of municipal supply.

In the literature review, divergence in opinion over whether RWH should be a primary or supplementary water source was identified. Findings from the rural study support those of Assayed *et al.* (2013), that RWH is appropriate for communities that do not have access to public water supply. However, to ensure year-round access to water, RWH must be coupled with another water source (Haque, Rahman & Samali, 2016).

8.2.3 Support for RWH Implementation

In the rural community, the KDWSP operated a structured programme to provide RWH to both the community as a whole and homeowners within the community. In contrast, in Mbarara, no formal RWH community initiative was identified. As a result, the impacts of RWH implementation at the two case study sites differed. For the KDWSP, the goal of the rural programme was not just to implement RWH, it was also to empower women, to engage the community and to finance water access. Findings from the focus groups suggest that these goals had been achieved. In the urban community, there was no structured programme, and so the only goal was for end users to reduce their water bills and improve the availability of water. As a result, in the urban community, RWH contributed to fewer of the community water security goals than in the rural study. RWH adoption can be successful without institutional support. However, in the absence of this support, a private contractor needs to be available to ensure good maintenance of systems.

Particularly among the urban focus group participants, lack of awareness of RWH was cited as a barrier to adoption of the technology. This may be a common barrier to RWH adoption across sub-Saharan Africa. A water practitioner with experience in Madagascar explained that:

> *'Uptake is low because awareness is low. People don't know about the technology and so don't know to adopt it. When successful installations take place, you see the snowball effect – everyone starts to request a system' (ST17).*

Policies to support the implementation of RWH could aim to improve awareness, but in the absence of this institutional support, as Staddon *et al.* (2018) have found, it is up to NGOs to encourage the uptake of RWH. For many communities, RWH may not be the most appropriate water-provisioning technology, but in regions with adequate rainfall, the findings from this study demonstrate that it can contribute to improving water security for the millions of people in sub-Saharan Africa who suffer from water access challenges.

Both the water quality and sanitary survey results were indicative of RWH systems that were, overall, well-maintained. End-users in the rural group attributed their ability to maintain RWH systems to the capacity-building support they had received by the KDWSP. In the urban study group, a lack of capacity-building support meant that domestic users outsourced the maintenance of their RWH systems to a private plumber. The apparent higher income of the urban users meant that they could afford the higher maintenance costs associated with outsourcing maintenance.

Abdulla & Al-Shareef (2009) note that the effective management of RWH systems influences both the water quality and the ability of communities to sustain RWH systems. As effective management of systems is dependent on external support provided by intermediary organisations, this support should be prioritised for the success of future RWH interventions in the sub-Saharan Africa region. Lee *et al.* (2016) suggest that this external support could be bolstered by policies that encourage the upkeep of RWH. Further research could examine how to incentivise the prioritisation of such policies in Uganda, where decentralised water supply appears to be under-supported by governmental institutions.

8.2.4 Climate Disruption

In the rural focus groups, participants noted that climate disruptions were having a significant impact on agricultural activities. As a predominantly agricultural community, changing rainfall patterns had inhibited the community's ability to generate livelihoods from agricultural activities. RWH played an important role in mitigating the impacts of shifting rainfall patterns, as the systems provided users with a 'buffer' of water storage in times of drought. This meant that they could continue agricultural endeavours despite prolonged periods of drought that had previously impacted crop growth.

In contrast, as the urban group were predominantly employed in non-agricultural activities, climate disruptions had less of an impact on income-generating activities and livelihoods. In addition, prolonged drought did not impede end-users' overall water access, as the urban case study users had adopted RWH as a supplementary water source and municipal water was still available throughout the dry period.

Kahinda, Taigbenua & Borotob (2010) and Boelee *et al.* (2013) find that RWH encourages community resilience to increased hydrological uncertainty by providing a buffer of water supply in times of drought. This was certainly the case among the rural cohort. Nonetheless, the reliability of RWH systems is vulnerable to climate change which is causing shorter, more intense downpours. Kiggundu & Wanyama (2018) believe that RWH can mitigate against the impacts of climate change, but tank sizing must take into account future climate scenarios and predictions.

While the literature identified that significant research has been carried out on how to optimise the tank storage volume so that it is compatible with the catchment area, there was no evidence that this practice was conducted among any of the twenty installations involved in the site assessments. Tank storage optimisation could reduce the incidence of tank overflow that was prevalent in the urban community and reduce the number of days that tanks are empty (Liaw & Tsai, 2004; Mishra, Adhikary & Panda, 2009).

For approximately one third of the year, the RWH systems in both the urban and rural case study could not provide users with water. Annual availability of water from RWH can be improved by increasing the size of the catchment and tank, and conserving water during the rainy season. Nonetheless, these both come with challenges. Cost and lack of awareness of how to size RWH tanks to match the catchment area were cited as barriers to increasing RWH tank size in the urban community. Increasing the size of the tank increases the capital cost required for construction and installation, and conserving water in the rainy season requires behaviour change and educational programming.

Gerlak *et al.* (2018) found that, in general, diversification of water sources increases climate resilience. The findings from the case study suggest that to achieve the goal of climate resilience, rainwater harvesting should be used as a complementary source of water. Reliance on multiple sources of water is a sensible response in environments such as south-west Uganda, where communities are accustomed to prolonged drought and high levels of rainfall.

8.2.5 Equitable Access

One of the core differences between the urban and rural case study groups was a lack of provision of water for the wider community. While community RWH systems provided water to the larger community in Kabale, no such initiatives were in place in Mbarara. The poorest community members, for whom domestic RWH is unaffordable, cannot access RWH without the facilitation of this community access, which must be subsidised by institutions or intermediary organisations. For their similar study conducted in Uganda, Staddon *et al.* (2018) found that intermediary organisations were essential for the upscaling of RWH in communities.

In Kabale, the RWH programme was implemented with equitable access at the forefront of programme delivery. Training of women on the construction and management of water systems aimed to empower female community members to control their own water supply and increase their skillset. Institutional RWH installations provided water access for the wider public at no cost, and so users who could not afford domestic RWH systems still had access to water at close proximity. The lack of a structured programme in the urban study meant that similar benefits for marginalised groups were not accomplished. A lack of financing mechanisms and institutional support in Mbarara meant that equitable access to rainwater was poor, with ability to self-finance the critical factor in dictating whether users had access to RWH.

When community access to RWH is facilitated, many of the other goals associated with water security such as affordability and conflict mitigation are subsequently achieved. Equitable access to RWH facilitates multiple benefits of wellbeing for user groups that typically have not derived benefit from much of the progress made towards the Sustainable Development Goals. One notable barrier to community access is a lack of structures in place to ensure a sense of ownership among users. This was identified as a challenge for the sustained upkeep of the community RWH systems in the rural study and highlights how the proactive role of an intermediary organisation is essential if the lowest income user groups are to benefit from RWH access. The interaction between equitable access, conflict mitigation and affordability of RWH services provides a good example of the strong interdependencies between the water security goals – where equitable access is achieved, there is a cascading effect on the ease with which the other goals can be achieved.

8.3 Interactions between Water Security Goals

The literature review highlighted that one of the benefits of using a 'framework' approach to study water security is that it allows for the complexity of the interaction between the water security goals to be mapped. Through the case study assessments, it became clear that the water security goals were strongly dependent on each other. For example, the analysis in both communities demonstrated that the quality of water from RWH depended on how well the RWH systems had been maintained. In Kable, this, in turn, was reliant on training and capacity building support from the KDWSP. Whether the systems were likely to be sustained over their lifespan was also reliant on how well the systems were maintained and managed.

In Kabale, equitable access to RWH systems relied on the poorest members of the community accessing funding mechanisms for support with the high capital cost. Equitable access was improved by good management of community systems, ensuring water was distributed across the community. Risk of conflict, notably violence towards women, was reported to be mitigated by household water access. There was strong evidence to suggest that RWH supports agricultural and microenterprise activities, however, these relied on year-round availability of water, the lack of which is one of rainwater harvesting's greatest drawbacks.

RWH has a high capital cost but, when compared to other available water sources such as municipal water or jerry-can water sold by local vendors, delivers a more affordable water source over the lifespan of the RWH system. Nonetheless, this affordability relies on RWH systems functioning over the duration of their lifespan and on financial subsidies.

Year-round availability of water is impacted by the annual distribution of rainfall, and both community's ability to better prepare for climate uncertainty was bolstered by water conserving activities that improved the year-round availability of water. While none of the RWH systems met the entirety of users' annual water demand, water conservation activities could ensure that water is available for a higher number of days per annum than is currently being achieved.

In Figure 31, these interrelations and co-dependencies are presented. The identification of the interrelations between each of the water security goals demonstrates that water security is very much a holistic framing of the human-water relationship. Strengthening each of the components of water security is fundamental to improving the overall water security of communities.

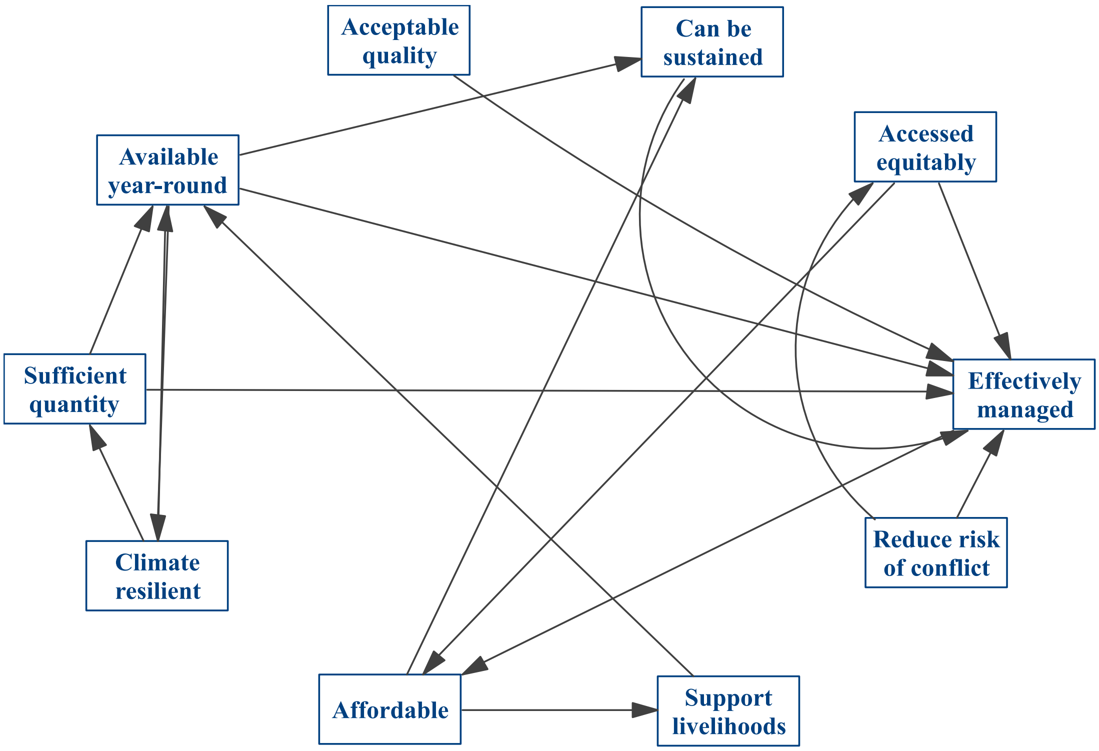


Figure 31 - Interrelations map demonstrating the co-dependency of the water security characteristics

8.4 Implications of Findings

RWH can meet water security goals for a variety of user groups, but its socioeconomic benefits are greatest for users who have no alternative on-site water access, which is likely to be among rural demographics. That said, the findings suggests that RWH cannot meet the total water needs of users in this region of Uganda, and so must be supplemented by alternative water sources. The implications are that water services providers must make it clear to end-users that in the climate of south-west Uganda, based on current tank-sizing practices, RWH is unlikely to provide on-site water for more than a third of the year.

The relationship between RWH and climate in the region is dichotimous. RWH can create climate resilience by providing a 'buffer' of water in times of drought. However, the functionality of RWH will be negatively impacted by future changes in rainfall patterns that generate shorter, more intense periods of rainfall and longer droughts. The most suitable way to mitigate the impacts of these changes is to ensure water storage is large enough to supply water to users over the lengthy period of drought, but this requires a higher capital cost for larger water storage tanks. Storing water for longer periods of time also increases the risk of contamination unless water treatment practices are carried out. To ensure RWH tanks are sized to provide adequate storage, educational programmes on tank optimization and financing mechanisms to help with the high capital cost are required. Policymakers and WASH NGOs should prioritise funding support for the poorest user groups if uptake of RWH is to improve across Uganda.

The findings presented in Chapters 6 and 7 demonstrate that certain actions can drive the successful adoption and use of RWH, resulting in better water security for end-users. For example, the 'self-supply' model adopted by the KDWSP in Kabale supports the expansion of RWH use, improving water access and users' ability to generate income from the RWH sector. This model was absent from the urban study group. However, it may have been the case that such a model was not needed and may not have worked for the urban user demographic, where most users were fully employed, and may not have had the will or need to generate income from building RWH tanks. The implications of the difference in findings between the two user groups is that different models of implementation are required to meet the needs of urban and rural user groups.

The findings from the two-case study demonstrate that there is no one-size-fits-all solution to implementing RWH. Instead, solutions should take into account local conditions and should be designed to function in harmony with these conditions. The water security framework used here for the assessment of RWH outcomes can help to identify which types of policies, mechanisms and incentives can increase the uptake of RWH, contributing to improved water security for both rural and urban communities.

9 CONCLUSION

In this section the purpose of this research project is reviewed, and the main research question and sub-questions are presented once more. The main conclusions that have been drawn from this research are presented along with a section that highlights the contribution to knowledge that this research provides. The limitations of the study are discussed, followed by recommendations for research that could be carried out to further understand the topics addressed in this thesis. The chapter closes with final remarks on the value of water security framings.

9.1 Review of Purpose

The aim of this doctoral research was to contribute to a better understanding of the drivers, barriers and outcomes of RWH use for communities in Uganda. A secondary aim of the research was to understand how water security concepts can be framed to assess the sociotechnical outcomes of access to rainwater harvesting. The water security framework developed through this research project provided structure to identify and assess the impacts of RWH on human wellbeing and socioeconomic development. The framework also provided a tool for post-project assessment of whether water services have been delivered in a way that meets community water security goals.

The research was driven by the following **main research question**:

‘What are the sociotechnical drivers, barriers and outcomes of rainwater harvesting use in communities in Uganda?

A series of sub-questions were developed to represent the various stages of research undertaken to answer the central research question:

Sub-question (1): How can the concepts associated with water security be framed to assess the sociotechnical outcomes of rainwater harvesting use in Uganda?'

Sub-question (2): To what extent have specific rainwater harvesting interventions met sociotechnical water security goals in Ugandan communities?

Sub-question (3) How do the drivers and barriers of RWH use differ between urban and rural communities in Uganda?'

9.2 Main Conclusions

In answering the above research questions, the following are the main conclusions of this research:

I. A new definition was developed that describes how decentralised water services can contribute to community water security. They should provide sufficient water of acceptable quality, which is affordable and available year-round. They sustain livelihoods and can be equitably accessed across all user-groups. These water services should minimise the risk of local conflict and boost community cohesion and climate resilience. The management of these services should be supported by local and national institutions so they can be reliably sustained over the long-term.

II. The most significant sociotechnical drivers associated with the adoption and use of RWH in the rural community in south-west Uganda were the opportunity for on-site water access where alternative water access required lengthy, and high-risk journeys, the opportunity to generate income through agricultural and entrepreneurial activities that required water, and protection against climate unpredictability, which caused lengthy and unexpected periods of drought. The adoption and sustained use of RWH was facilitated by the presence of a local NGO that carried out training on the construction and maintenance of RWH systems. This meant that end-users had the knowledge to maintain and sustain their RWH systems so that they were in a condition to provide water of acceptable quality. Barriers to the adoption of RWH in the rural community included the high capital cost of RWH systems (despite financial support from the implementing NGO), and limits on the year-round availability of water from RWH.

III. The most significant sociotechnical drivers associated with the adoption and use of RWH in the urban community in south-west Uganda were dissatisfaction with the centralised, piped water supply due to perceived poor water quality, interruptions in supply and a sense that centralised water services did not provide good value for money. Despite the high cost of RWH installation, the opportunity to reduce the cost of municipal water bills was a strong incentive for the adoption of RWH. Barriers to the adoption of RWH in the urban community included a lack of financing mechanics to support funding for RWH installation, a lack of awareness of RWH among community members, and the fact that water institutions prioritised centralised water access over decentralised access for urban inhabitants.

IV. The challenges and opportunities associated with community rainwater harvesting differed between the urban and rural case study groups because of socioeconomic, environmental, institutional and contextual factors. The lower-income rural group were incentivised to adopt RWH because of a lack of alternative water sources at close proximity and because of a need for a reliable water supply to facilitate agricultural activities that were being disrupted by shifting rainfall patterns. The higher-income urban case study group were incentivised to adopt rainwater harvesting because of dissatisfaction with the centralised municipal water services. In the rural community, as is common in rural communities in low-resource settings, RWH was delivered by an NGO that focused on capacity-building, women's empowerment and developing a 'self-supply' model. This led to several positive socioeconomic outcomes associated with the delivery of the RWH programme, including water access for residents who could not afford household RWH. In the urban community, there was no evidence of institutional support for RWH delivery. Instead, end-users sought private plumbers to install and maintain RWH systems. Community members who could not afford the high capital cost associated with RWH received no financial support. The findings suggest that RWH is an appropriate water-provisioning technology for the two contrasting user groups, but wider socioeconomic benefits were more apparent from the model of delivery in the rural community.

V. RWH is most appropriate as a supplementary water source. The biggest drawback of the technology is that it is unlikely to satisfy the entirety of users' water demand throughout the year. In Uganda, the bi-annual rainy season allowed for water collection over two periods of the year. Nonetheless, consistent water access was still a challenge because of prolonged periods of drought between the rainy seasons and issues with tank sizing. As a result, it is recommended that RWH is adopted as a secondary water source where alternative water supply is available to ensure water security for the days of the year when RWH tanks are empty.

VI. RWH has the biggest impact on community socioeconomic growth where livelihoods and productivity rely on good water access and where the poorest members of communities are supported with financing mechanisms and training on RWH system management. Local and national institutions are essential in providing this support and engaging communities to understand the role that RWH can play in improving their water security.

9.3 Contribution to Knowledge

This study has bridged the gap between the conceptualisation of water security and the assessment of real-world techniques to improve water security. The role of this research has been to understand how framings of water security can guide the assessment of the outcomes of water access. By including goals and metrics with which to assess water security, the framework provided a new structure, not only to define water security, but also to guide the identification of the outcomes of water access. Unlike previous research, the framework developed here put the sociotechnical outcomes of water access at the forefront of the relationship between RWH and water security. This approach has allowed for (a) a better understanding of how community water needs can be satisfied and sustained by rainwater harvesting and (b) a clearer idea of the positive and negative outcomes of rainwater harvesting projects in Uganda, and how these can be managed.

While initial framings of water security were underpinned by the need to overcome water scarcity, new framings have evolved to describe the nature of water-society relationships. This research thesis adds a further step in the evolution of water security framings by demonstrating how these framings can be applied to identify the sociotechnical outcomes of water access.

One of the stakeholders interviewed for this thesis hypothesised that water security framings are *'probably just putting nicer words to something that most people are already doing*'. Even if that is the case, and water security framings are principally a tool to communicate the human-water relationship, then this method of communication allows organisations to identify the factors they should prioritise when delivering decentralised water services. The water security framing presented here can help to structure the identification and assessment of the less tangible impacts of water access.

In several countries across the world, rural populations do not have access to centralised water services. In the absence of these services, decentralised water services are essential. Where urban populations have access to centralised water services, end-users are sceptical about the price and quality of service delivery and so look to decentralised services to supplement their water supply. Comparisons between urban and rural communities, which allow clearer insight into how various community conditions influence water security, had not been found through the literature review. Through the urban/rural community comparison of this study, this research provided unique insight into how the socioeconomic, institutional and environmental conditions that influence RWH use, and water security differ for these two types of community.

In the Introduction, it was highlighted that, despite recommendation from the IPCC that RWH can improve the reliability of water access in sub-Saharan Africa, uptake of RWH in the region is below targets set by the United Nations. Scholars have called for the potential benefits of RWH, other than to purely provide and preserve water, to be explored. They have noted that particular emphasis should be placed on identifying how institutional and socioeconomic support can improve the level of community acceptance of RWH. To date, very few academic studies have focused on assessing decentralised water services by the goals of water security. This research project has provided insight for water practitioners, researchers and stakeholders involved in the delivery of decentralised water to better understand how these services can meet the differing needs of rural and urban communities.

9.4 Limitations of Findings

In order to conduct this study, the researcher relied on the presence of local organisations in Uganda to support the data collection processes. Without the support of these organisations (Afrinspire, Mbarara Plumbers' Association and the Kigezi Diocese Water and Sanitation Project), access to the communities that took part in this study would have been much more challenging. One implication of this is that the RWH systems assessed in this study are likely to have been of a higher quality than if a randomly selected sample of systems were assessed. Whether intentionally or not, the partner organisations in Kabale and Mbarara are likely to have selected RWH systems that would present a positive impression of RWH in the region. The consequence of this is that the assessments presented in this research may not have provided a complete representation of all of the barriers to RWH adoption in the community. Certain drivers and barriers to RWH adoption in the community may have been overlooked, but those that have been presented in this research have been evidenced by multiple data points.

The availability and desire of community members to participate in the study was a factor that determined which community members were interviewed either one-to-one or through the focus group sessions. The findings may have been influenced by positive selection bias – those people who had positive experiences with RWH were more likely to be willing to be involved in the study. This may have meant that the positive outcomes of RWH were more dominant in the findings than if a random sample of participants were selected. Nonetheless, the drawbacks of RWH were explored, discussed and presented in this study in detail, mitigating this selection bias. Additionally, several community members who had not adopted RWH were selected for the focus groups, further mitigating this bias. Research to identify further barriers to RWH adoption and use could include assessments of communities where RWH implementation has failed. This would allow for a deeper understanding of the barriers to adoption.

Whilst the content of the water security framework was subjected to member checking and was applied for research practices, its utility as a post-project assessment tool for water practitioners has not been assessed. Further work may be needed to confirm the framework is of use to practitioners in identifying the outcomes of access to water services. The framework encourages significant mixed-methods data collection, which may be impractical for practitioners who have limited resources for post-project assessment. With that in mind, for practical purposes, the framework may be of most use when designing water services, ensuring practitioners are well-informed on the sociotechnical outcomes that should be prioritised for end-user satisfaction.

9.5 Recommendations for Further Work

This study has identified some of the drivers, barriers and outcomes of RWH use in Uganda. Further research should now focus on identifying specific policies and mechanisms that can support the uptake of RWH across Uganda and sub-Saharan Africa more widely.

Through this research, it was found that high capital cost, lack of awareness and absence of intermediary organisations were all barriers to the uptake and sustained use of RWH. To improve uptake, mechanisms to overcome these barriers, supported by local and national institutions could be identified by scholars and WASH practitioners. There is a need for further research into how policy can support efforts to ensure water security.

As the high capital cost of tanks was deemed to be one of the most significant barriers to RWH adoption in the region, opportunities to reduce the overall cost of RWH systems using locally available materials should be assessed. In Kabale, two households that had adopted low-cost mortar jars were assessed. At both sites, water quality from RWH did not meet WHO standards, so further research should aim to identify how to make affordable RWH systems widely available in Uganda without compromising on water quality.

Over the coming decades, solutions to improve water security for rural and peri-urban populations are likely to include hybrid models of decentralised and centralised water supply and so further understanding of how the two service types can complement each other, is needed. This study has focused specifically on one decentralised water service – rainwater harvesting. Further research could assess the contribution to water security of alternative decentralised water services, including hand-dug shallow wells, groundwater collection services and gravity-flow schemes prevalent across sub-Saharan Africa. This would provide further knowledge on the contribution of decentralised water services to water security and could help with deciding on the most appropriate water service for the arid and semi-arid conditions found in several sub-Saharan African nations.

The water balance model adopted as a method for this research project could be developed further to predict the impact of various future climate scenarios on the effectiveness of rainwater harvesting in different climatic zones. This would assist further with decision-making when choosing between various decentralised water services, helping to identify if RWH is an appropriate intervention or if alternatives are more suitable for future climate scenarios predicted over the lifespan of RWH systems installed today.

In Chapter 8, interrelations between the goals of water security were discussed. There is a need to further understand how the various characteristics of a water secure community influence and impact each other so that stakeholders can identify where to prioritise funding and efforts to improve water security. Systems dynamics modelling such as that used by Bitterman *et al.* (2016) would allow for these interrelations to be further understood.

9.6 Final Remarks

By 2050 it is estimated that more than half of the world's population will be living in water-stressed regions. Achieving clean water access will be at the forefront of the international agenda in the coming decades. Strategies to ensure this access lie in a combination of the technical, socioeconomic and political and can be implemented at all scales, from setting globally recognised targets such as Sustainable Development Goal 6, to ensuring access to affordable household water treatment technologies.

Water security provides a framework to develop these strategies and to assess whether they are working. It allows for the complex nature of the relationship between humans, water and the environment to be better understood. It encourages clean water access to be prioritised, ensuring that the current and future water needs of all communities can be met, even when faced with substantial risks such as climate change and demographic transition.

Water security has become a critical component of the sustainable development discourse. The water security framework presented in this thesis provides a tool for water practitioners, researchers and stakeholders involved in the delivery of water services to ensure that social, environmental, economic and technical goals are prioritised. This research has provided an example of how approaches to water access can be reframed, so that water is rightly viewed as the lynchpin of human wellbeing and sustainable development.

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11 APPENDICES

I. Stakeholder Interview Guide (Water Security Framework)

Interview objectives

1. To identify, according to practitioners, the key attributes of a water secure community.
2. To explore how water practitioners implementing decentralised water provisioning strategies/technologies understand and operationalise the term water security.
3. To identify how community-level water security is currently assessed by water practitioners.

Interview Structure: Introduction

- Background on interviewee organisation including core areas of focus (WASH, children, vulnerable populations, protection, medical access etc.).
- Experience of interviewee (WASH specialist, M&E specialist, management, country coordinator etc.).

Water security knowledge and understanding:

- Have you come across the term ‘water security’? If so, where?
- Could you explain what you believe water security refers to?
- Does your organisation have a specific interpretation of water security?
- In your opinion, how does water security differ from other terms used to describe water access?
- Can you describe some characteristics that make a population ‘water secure’?

Current methods of assessment of WASH projects:

- Talk me through how WASH projects are currently assessed at your organisation.
- What metrics are used to measure success?
- What does a successful WASH project look like in your opinion?
- What are your organisation's core goals when implementing a water-provisioning project?
- Are the same assessment methods used for every project that your organisation carries out?

The role of water security in project assessment and implementation:

- Do you think current methods of assessment of the 'success' of water-provisioning interventions are adequate? If so, why? If not, why not?
- Do these methods help to identify the relationship between water and socioeconomic development? Is this a relationship your organisation considers when implementing WASH projects?
- When implementing WASH projects how much of a priority is equitable access? How do you measure equitable access to a water source?
- When implementing WASH projects, how much of a priority is sustainability? Can you define what is meant by the sustainability of a WASH project?
- Do you ever consider whether a water-provisioning intervention can help beneficiaries to manage climate risk? Can you give examples of climate risks your beneficiaries face?

Decentralised water interventions:

- Given our discussion above, how do you think decentralised water services could contribute to water security for populations in low-resource settings?
- Do you view rainwater harvesting as a climate adaptation strategy? If so, why? If not, why not?
- What are some barriers to the implementation & adoption of rainwater harvesting for rural and urban communities in sub-Saharan Africa?

II. Site Assessment and End-User Interview Guide

Assessment & interview objectives

1. To identify the state and quality of the rainwater harvesting systems at each site.
2. To provide an understanding of the end-users' satisfaction with their RWH system.
3. To collect data on the contribution of the RWH system to the end-users 'water security' as defined by the framework presented in Chapter 4.

Site assessment questions (Answered by researcher through visual check)

1. From what material is the roof constructed?
2. What is the size of the roof?
3. How many roofs are there in the catchment?
4. From what material is the guttering made?
5. What is the volume of the RWH tank?
6. What material is the tank made from?
7. Is the RWH system on a household or an institution?

End-user interview guide (to be answered by interviewee)

Demographics

1. How many people live at this property/access water from this site?
2. How many buckets of water does each person consume per day? (A bucket is 10 litres)
3. What is your highest level of education?
4. What is your profession?
5. What do you use the water from the RWH system for?
6. Do you carry out any agricultural activities? If so, what?
7. Do you carry out any entrepreneurial activities? If so, what?
8. Is there ever conflict in your household/community over who can access the water?

9. Have you ever been consulted about water access projects in your community?

RWH systems

10. Is RWH your primary water source? If not, what water source is your primary source?
11. Does your RWH system ever overflow? If so, when?
12. Is your RWH tank ever empty? If so, when?
13. Do you have enough water year-round?
14. When was the RWH tank installed?
15. Who installed the system?
16. Were you involved in the installation?
17. Were you trained on proper installation practices?
18. How much did the system cost?
19. Did you pay for the system in its entirety? If not, how much did you pay?
20. Did you pay upfront, or were you helped through micro-financing?
21. How much does it cost you to maintain the tank (yearly)?
22. Does someone maintain the system? If so, how often is the system cleaned?
23. Is it clear whose role it is to maintain the system?
24. How often does the system get blocked/break?
25. If the system breaks, how do you fix it? Do you do it yourself?
26. On a scale of 1-5 how confident do you feel in maintaining the system?
    a. 1-Not confident at all, 2-Under-confident 3-Fairly confident 4-Very confident 5-Extremely confident
27. Does anyone ever check on your tank without you asking them to?
28. How would you rate the taste of the water from the tank?
    b. 1-Terrible, 2-Bad, 3-Ok, 4-Good, 5-Excellent
29. Do you, or does anyone in your family ever have diarrhoea or vomiting? If so, how often?
30. Do you ever share the water from the RWH system with anyone outside of your household?

31. Do you treat the water before drinking? If so, how?

Local environment

32. What is the alternative source of water?
33. Do you still use your alternative water source?
34. Do you have access to water all year round?
35. How many days a year do you expect to use water from RWH?
36. How many hours a day do you spend accessing water?
37. Has the RWH system reduced the number of hours a day you spend accessing water? If so, by how many hours? What do you use that time for now?
38. Do you ever feel concerned about flooding? If so, when? What worries you?
39. Do you every feel concerned about drought? If so, what worries you?
40. Do you find the local climate predictable?

III. Focus Group Guiding Questions

Focus Group Objectives

1. To identify the demographics of the community.
2. To give voice to community members who do not have RWH.
3. To understand the broader state of water access in the community.
4. To triangulate findings from end-user interviews with broader findings from the community.
5. To understand the community consensus on the opportunities and challenges association with RWH.

Focus Group Process

An activity-oriented approach was adopted for the focus group discussions. The activity-oriented approach included rating, ranking, choosing from alternatives, picture sorting, and storytelling. Sessions lasted between 45 and 90 minutes.

Focus Group Question Guide

1. **Demographics:** What is the living situation for each participant? Where do they live in the community? What number of people are in the household? Who are the people living in the house? What do they do? Which groups would you class as 'vulnerable'?
2. **Water usage:** Where do people get their water? Do they get it from piped sources? Gravity-feed? Community pump? The river? What do you use water for?
3. **RWH:** How many people in the group use RWH? Do they have RWH systems installed in their homes or do they use water from community systems? Which would you prefer?
4. **Water quality:** How would you rate the taste of the water from RWH tanks?
    a. 1-Terrible, 2-Bad, 3-Ok, 4-Good, 5-Excellent
    b. How does this compare to water from community springs or the river? Better or worse? Do you ever get sickness: diarrhoea, vomiting, stomach-

ache? Is the water cloudy? What source do you think provides best quality water? Why?

5. **Water quantity & availability:** Do you have enough water year-round? How do you define enough? Which times of the year do you not have enough water? Do you ever have too much water? If so, what do you use the excess water for?
6. **Climate resilience:** Has the way people accessed water changed in recent years? How did they get their water before? Does the community ever suffer from water-related risks? If so, how do these events impact their day-to-day lives (provide specific descriptions)?
7. **Affordability:** Do you pay for your water? How much does it cost? To whom do you pay? How often do you pay? Do you pay monthly or in a lump sum? Is there any financial support? From whom? Do you find your water expensive? Have you ever paid for a RWH system?
8. **Sustainability:** Are you worried your water access will change? Are you involved in the management of your water access? Do you find it easier to manage your own or when an institution manages it? Do you feel like you have ownership of your water access? Would you prefer to have this decentralized water or government water?
9. **Equitable Access:** Does everyone in the community have equal access to water? Do you prefer having community water or household water? Are there any groups in the community that are not allowed water? Why? How does access differ between men and women? Do the people without household water wish they had household water access? What do you do if you can't get access to your normal source of water?
10. **Management:** Who controls the water points? Who is in charge of maintaining them? Have you ever been trained in maintaining community water systems?
11. **Conflict:** Does conflict ever exist in your community over water access? If so, who is involved? Which actors are in charge of diffusing conflict? Over which points is there disagreement in the community regarding water access?
12. **Livelihood generation**: Do you ever carry out any agricultural activities with the water from RWH systems? Do you ever carry out any entrepreneurial activities

with water from RWH systems? Does the length of time to collect water ever stop you from working/learning? If you had to spend less time collecting water, what would you use that time for?

IV. Water Quality Testing Procedure

Collection & Testing Procedure

The procedure for testing for thermotolerant coliforms is as follows:

a. Sample water is passed through a sterile filter.
b. Any bacteria present are caught on the filter.
c. The filter is placed on a pad soaked in liquid growth medium which feeds coliform bacteria and inhibits the growth of other bacteria.
d. The samples are incubated at 44^{o}C in the DelAgua incubator, this ensures only thermotolerant bacteria grow.
e. During the incubation period, which lasts 16-18 hours, if thermotolerant bacteria are present, they multiply many times to form colonies that can be seen with the naked eye.
f. Thermotolerant coliforms are recognized by their ability to produce a colour change (from red to yellow) in the culture medium.
g. Results are expressed as colony-forming units per 100ml of water (CFU/100ml) (DelAgua, 2014).

Quality Assurance and Quality Control

For each round of testing, 16 samples can be tested at once. DelAgua recommends that for each test site, 3 petri dishes are dedicated to each site. This includes a negative and two actual samples: one sample of 100ml, and one sample of 10ml. One 'stack blank' plate should be included for each set of 16 samples (the maximum number of samples that can be tested at once). A 'stack blank' demonstrates effective sterility of the plates and the media, which ensures that any positive results are not originating from contaminated plates or media (DelAgua, 2014).

Although not specifically recommended by DelAgua, a known contaminated sample was also included in each test. This sample was taken from communal drainage points in each location. The purpose of this was to demonstrate that if contamination were present, it would be identifiable through the incubation process. For each of the 20 sites tested, 2 samples were taken in the September 2018 field visit, and 2 samples were taken in the July 2019 visit. These 4 samples included 1 x 100ml sample + 1 x 10ml sample tested in one round of incubation, and the same again in the second round of incubation. The core limitation in the number of samples that can be tested using a DelAgua kit is time. Samples must be tested within 4 hours of being collected, and the sample preparation and incubation process takes approximately 18 hours.

Once the 'stack blank' plates were checked, the sample negative plate was checked. If this was negative, then the samples were then reviewed. Colonies were then counted on the sample dishes. All yellow colonies that have a diameter between 1mm and 3mm were measured with callipers and then counted. These colonies were then converted into the number of thermotolerant samples per 100ml. For the 10ml samples, the number of colonies identified was multiplied by 10 (DelAgua, 2014) .